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A MULTIBURST FALLOUT MODEL FOR OPERATIONAL TYPE STUDIES.(U)
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A MULTIBURST FALLOUT MODEL

FOR OPERATIONAL TYPE STUDIES

THESIS

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Capt USAF

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A MULTIBURST FALLOUT MODEL

FOR OPERATIONAL TYPE STUDIES.

9 Master's THESIS,

12 86

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

by

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Capt USAF

Graduate Strategic and Tactical Sciences

11 March 1981

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Preface

The study of radioactive fallout from nuclear detonations is of great interest in this time of debate over the proposed MX missile field. A counterforce attack against this complex could consist of thousands of large yield nuclear weapons detonated on or near the ground. Such an attack could have more far-reaching consequences than most military planners consider. A highly survivable, mobile missile system would have little value to the millions of people killed from the fallout produced by such a counterforce attack.

Presented within is a simple, efficient procedure for accurately determining this collateral damage of fallout for any scenario involving many bursts. This method is designed for an operational planner to easily "scope the problem" without utilizing much computer time.

I am grateful to Dr. Charles J. Bridgman for his guidance in the development of this procedure, and to my lovely wife, Michaela, for her patience and support.

John F. Crandley, Jr.

(This thesis was typed by Sharon A. Gabriel)

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Abstract

A method is developed for calculating fallout deposition downwind from a massive nuclear attack on a small target area over a short time span. This is accomplished using existing smear codes and replacing their existing horizontal activity distribution with an approximating function. This function is the difference between two cumulative normal functions which are shown to result from superposition of individual bursts. A comparison is made between the contours predicted by this new code and contours predicted by the old, time-consuming, iterative procedures. The new code has been employed in several different scenarios involving the proposed MX field to determine the resulting dose contours from a massive attack against that field.

A MULTIBURST FALLOUT MODEL FOR OPERATIONAL TYPE STUDIES

I. Introduction

A new Intercontinental Ballistic Missile (ICBM) system will be deployed in the Western United States within the next several years. This new system, designated the MX, will greatly enhance the survivability of the land-based leg of the Triad. This survivability will be accomplished through mobility; a single missile will be shuttled randomly among 23 shelters on a racetrack. The current proposal calls for 200 missiles to be purchased, with 200 racetracks to be built in Utah and Nevada (Ref 1:3).

This method of "hiding" the MX missiles creates tremendous problems in targeting for any enemy. One possible targeting option would be to attempt to destroy as many MX shelters in as short a time as possible. This option would have a high probability of destroying a large percentage of the MX missile force, while interfering with the command, control, and communication necessary to effect a retaliatory strike. Also of great concern is the corresponding downwind fallout effects from such a massive strike. There are several single burst nuclear fallout models available which could predict this collateral effect by superposition of individual burst fallout patterns.

Presently there are many different individual burst models being used by many different government agencies. Most of these models have their analysis based on a study done by the Weapons Systems Evaluation Group (WSEG-10) in 1959. However, Bridgman and Bigelow (Ref 2) have recently shown that the heart of the WSEG calculations is in error. They proposed an alternative method of calculation, which was used by Colarco (Ref 3) to construct an improved single-burst fallout code for operational type studies. Colarco's code produces results which are closer approximations than WSEG-10 to the Defense Land Fallout Prediction System (DELFIC). DELFIC is considered by many to be the benchmark of fallout computer codes.

One of the unfortunate aspects of these single-burst codes is that they cannot easily compute the effects of many bursts within a relatively small target area (such as an MX field). Fallout analysis of a counterforce attack on a missile field (or similarly distributed target) is now done by superpositioning hundreds of individual bursts by an iterative procedure. Because of the computer time needed for these iterations, this is a slow and expensive process. Also, because of computer limitations, this may not be a completely accurate procedure.

In the following chapters, a method will be developed to produce a fast-running computer code to accomplish multi-burst calcualtions without the need for superpositioning.

This code will be designed for operational use; that is, it will be a fast, inexpensive tool for operational analysts to use in predicting a reasonably accurate fallout deposition. This code will then be applied to a counterforce scenario against the MX field in Utah/Nevada. The results from this study will then be compared to the results obtained from using WSEG-10 calculations in the same scenario.

II. Calculation of the Multiburst Distribution

WSEG-10 predicts fallout dose rates on the ground with the following equation (Ref 4:17):

$$\dot{D}_1(x,y) = k \int_0^{\infty} f(x,y,t') \, g(t') \, dt' \tag{1}$$

where k is a source normalization constant, $g(t')$ is the activity deposition rate, and $f(x,y,t')$ is the normalized horizontal activity function. This activity function is a bivariate normal function with a time varying standard deviation in the cross wind direction:

$$f(x,y,t) = \frac{1}{\sqrt{2\pi}\,\sigma_x} e^{-\frac{1}{2}\left(\frac{x - V_x t}{\sigma_x}\right)} \cdot \frac{1}{\sqrt{2\pi}\,\sigma_y(t)} e^{-\frac{1}{2}\left(\frac{y}{\sigma_y(t)}\right)} \tag{2}$$

where x is the downwind distance, y is the crosswind distance, t is time and σ is the standard deviation. V_x is assumed to be a constant wind which rotates uniformly with altitude. This results in a constant value of wind shear for the determination of $\sigma_y(t)$.

It can be seen that Eq (2) can be written as

$$f(x,y,t) = f(x,t) \cdot f(y,t) \tag{3}$$

With this substitution it can be shown (Ref 5) that Eq (1) reduces to:

$$\dot{D}(x,y) = k \frac{g(t_a)}{V_x} f(y,t) \tag{4}$$

where t_a is arrival time of the cloud and

$$f(y,t) = \frac{1}{\sqrt{2\pi}\, \sigma_y(t)} e^{-\frac{1}{2}\left(\frac{y}{\sigma_y(t)}\right)^2} \tag{5}$$

It is obvious from Eq (5) that $f(y,t)$ is a normal function describing the crosswind spread of a single nuclear cloud. If two or more clouds are in close proximity and merge at some point to become one large cloud, a single normal function will no longer account for horizontal activity; there will be some cumulative effect from each contributing single-burst cloud. The fallout on the ground from this new, large cloud will still be described by Eq (4), except that $f(y,t)$ will no longer be given by Eq (5).

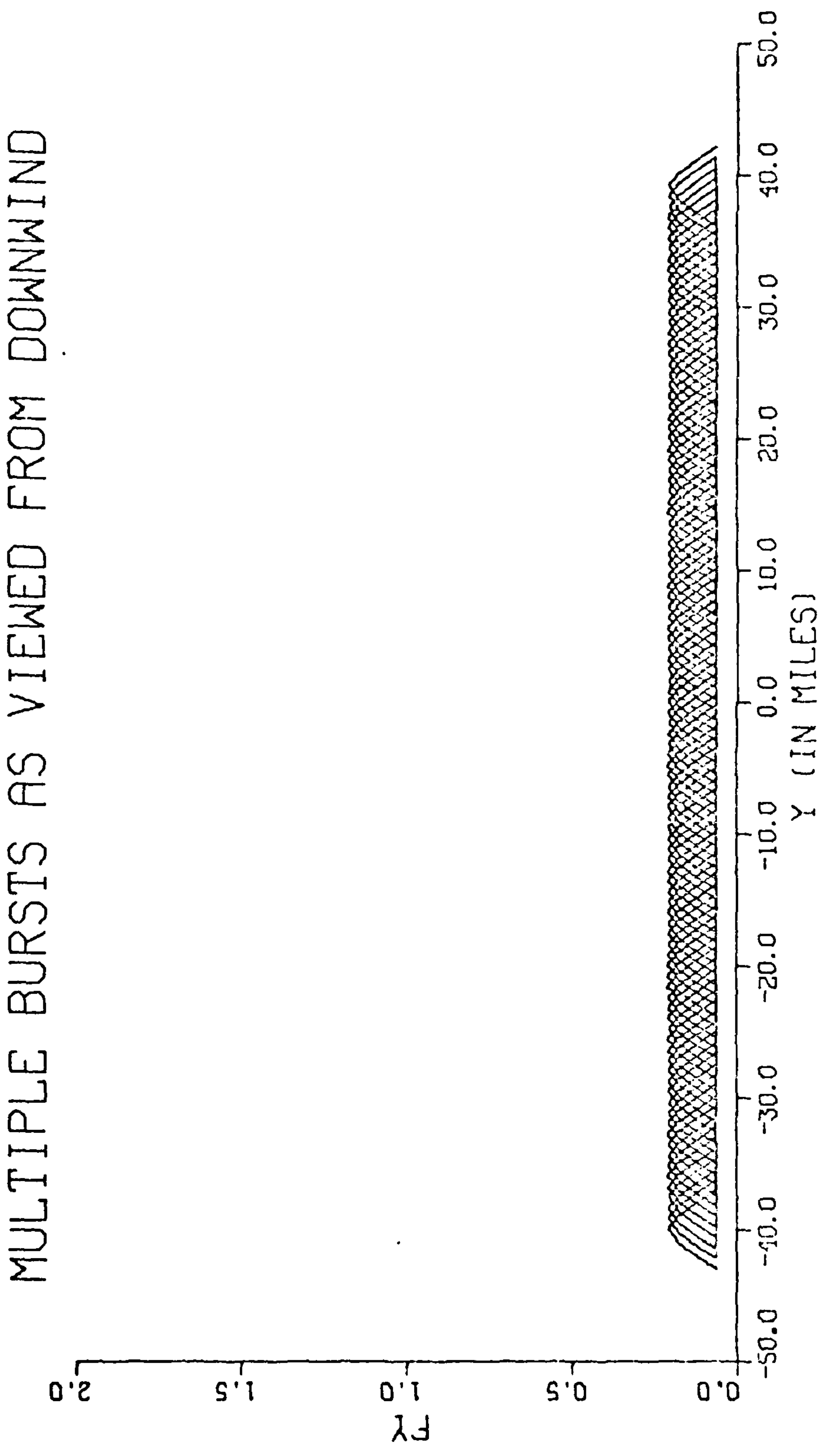
$f(y,t)$ for Multiple Bursts

If an observer were standing some distance downwind from a target complex (for example, a missile field) and was able to observe a large-scale nuclear attack on that complex, he would initially see many single nuclear clouds rising from the surface. If this particular attack were

100 one megaton detonations, all going off within a very short time of one another, and distributed uniformly along an 80 mile line perpendicular to the wind direction, then the observer would see 100 individual overlapping clouds. If the horizontal activity distribution within each cloud along this line is given by Eq (5), then the observer would see 100 normal functions, as in Figure 1. Note that y is now the crosswind distance as measured from the center of the target field.

It can be seen from Figure 1 that any point downwind from this line of clouds will receive activity from not only the single cloud directly upwind from this point, but also from adjoining clouds. This additional activity becomes even more pronounced as the clouds begin drifting with the wind as the horizontal activity standard deviation, σ_y, increases with time (as per the WSEG-10 analysis). The total activity at any point downwind can be found by finding the contribution of each single cloud and adding all 100 contributions together. If the standard deviation, σ_y, is large with respect to the intercloud distance, the addition operation can be replaced by an integral:

$$f(y,t) = \frac{N}{W} \int_{-W/2}^{W/2} \frac{1}{\sqrt{2\pi}\,\sigma_y(t)} e^{-\frac{1}{2}\left(\frac{y-y_o}{\sigma_y(t)}\right)} dy_o \qquad (6)$$



MULTIPLE BURSTS AS VIEWED FROM DOWNWIND
FY
0.0
0.5
1.0
1.5
2.0
Y (IN MILES)
-50.0
-40.0
-30.0
-20.0
-10.0
0.0
10.0
20.0
30.0
40.0
50.0

Figure 1

where $w/2$ is the half-field width (in the example, 40 miles) and N is the total number of bursts (here, 100). This function can be easily evaluated if it is split into two parts:

$$f(y,t) = \frac{N}{w}\left[\int_{-\infty}^{w/2} \frac{1}{\sqrt{2\pi}\,\sigma_y(t)} e^{-\frac{1}{2}\left(\frac{y-y_o}{\sigma_y(t)}\right)^2} dy_o \right.$$

$$\left. - \int_{-\infty}^{-w/2} \frac{1}{\sqrt{2\pi}\,\sigma_y(t)} e^{-\frac{1}{2}\left(\frac{y-y_o}{\sigma_y(t)}\right)^2} dy_o \right] \tag{7}$$

which is easily transformed into

$$f(y,t) = \frac{N}{w}\left[\int_{-\infty}^{\frac{y+w/2}{\sigma_y(t)}} \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}z^2}\, dz \right.$$

$$\left. - \int_{-\infty}^{\frac{y-w/2}{\sigma_y(t)}} \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}z^2}\, dz \right] \tag{8}$$

by letting

$$z = \frac{y-y_o}{\sigma_y(t)} \tag{9}$$

and

$$dz = \frac{-dy_o}{\sigma_y(t)} \tag{10}$$

Thus, $f(y,t)$ for many bursts is the difference between the cumulative normal functions for two different arguments. When this function is used in Eq (4), the total dose rate for any point downwind can be found. A graph of this function is presented in Figure 2, with the 100 single cloud distributions added for comparison.

Computer solutions for dose rates from Eq (4) would be quick and simple except for the integrals in the multi-burst $f(y,t)$. Therefore, the following approximation was used for the integrals in Eq (8) (Ref 9:932):

$$P(z) = 1 - \frac{1}{2}(.196854z + .115194z^2 + .000344z^3 + .019527z^4)^{-4} \quad (11)$$

where z is the upper limit of each integral. The difference between the two integrals was then multiplied by the number of detonations and divided by the field width to produce a numerical answer for $f(y,t)$. This number was then used in Eq (4) to produce dose rates.

As will be seen in the next chapter, dose rates from Eq (4) using this new $f(y,t)$ agree very well with dose rates derived by addition or superposition. However, several cautions need to be mentioned. This $f(y)$ function is meant to be used in situations where there are many bursts in a relatively small physical area. Also, the individual bursts positioned on the field width line cannot be more than one

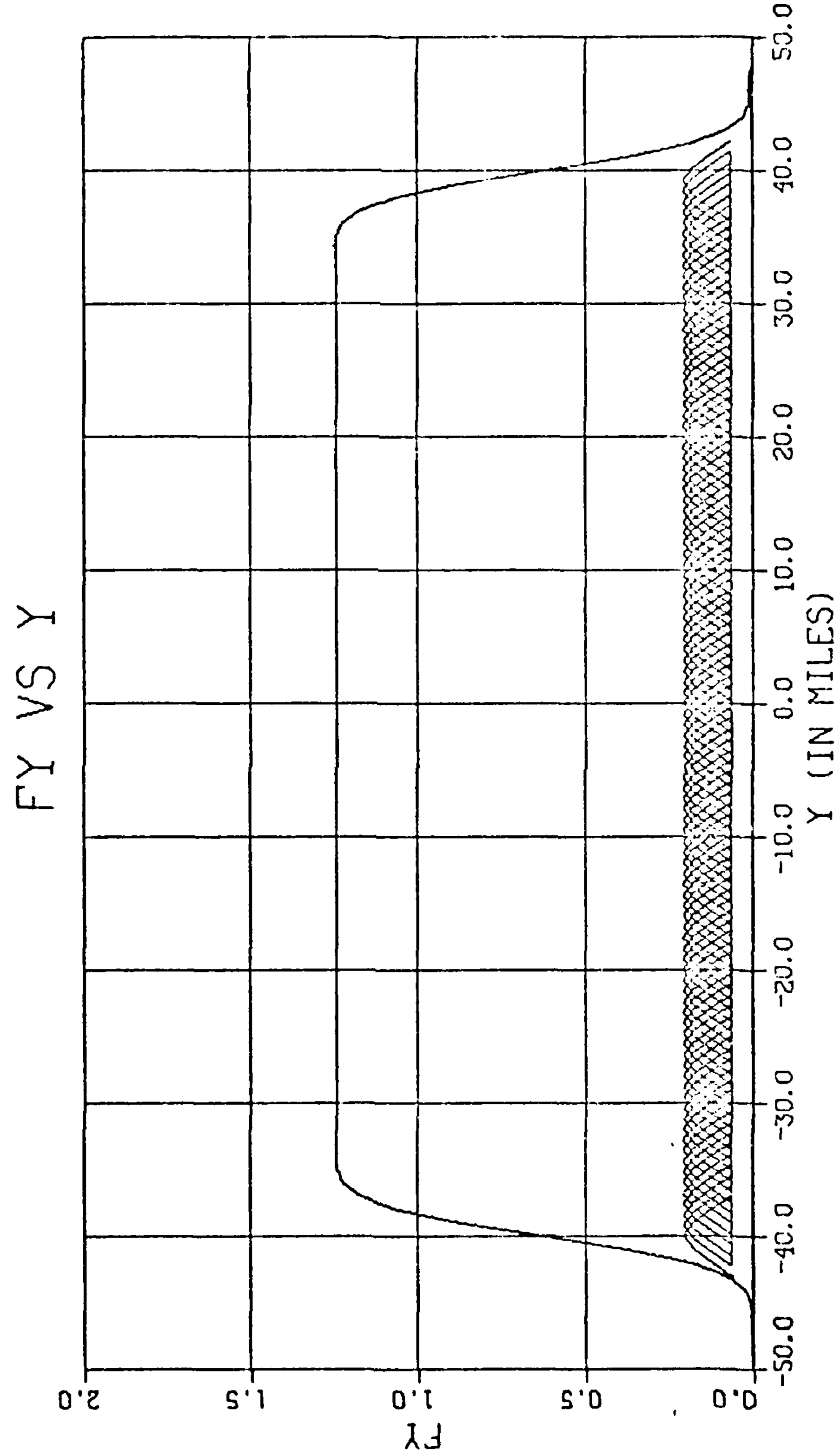

FY VS Y
Y (IN MILES)
FY
-50.0
-40.0
-30.0
-20.0
-10.0
0.0
10.0
20.0
30.0
40.0
50.0
0.0
0.5
1.0
1.5
2.0

Figure 2

standard deviation apart; that is, the number of bombs detonated in a defined area (the bomb density) must be large enough to allow the multiburst f(y) function to approximate the cumulative effect. Smaller bomb densities must be treated as an aggregation of single bursts.

III. Validation of the Multiburst Distribution

Any model must, by necessity, be shown to actually conform to the reality it purports to represent. There are several ways in which a model can be validated, with most validation methods comparing model results to actual data. As there is little data available on downwind fallout dosages from multiple bursts, a different approach was necessary. This involved a comparison between the results of the new model and results derived from an iterative superpositioning method of the same scenario.

Scenario

A scenario involving a counterforce attack against the missile field at Whiteman Air Force Base, Missouri (Ref 7:32) was used as a basis for comparison. This particular missile field encloses 150 silos in an area roughly 90 miles on a side. Two one-megaton devices were then simultaneously detonated at each silo, for a total of 300 bursts. These 300 bursts were then distributed evenly on a 98 mile line perpendicular to the average west wind of 20 miles per hour, and a shear of one per hour. Fifty percent of the yield of each burst was from fission. The coordinates of the contour lines of the following unit time reference dose rates were then computed: 1000 roentgen/hour (r/hr), 500 r/hr, and 100 r/hr.

Description of Superpositioning Procedure

A single burst code similar to Colarco's model (Ref 3) was used for the iterative procedure. A grid was established with 2000 miles on the x (downwind) axis and 182 miles on the y (crosswind) axis. The x axis was broken down into 201 increments, while the y axis was divided into 27. For more efficient computer operation, the 150 silos were broken down into 15 groups of 10 silos per group. These 15 groups were then placed on grid line $x = 6$ and on every grid line between $y = 7$ and $y = 21$, resulting in 15 silo groups evenly distributed on a north-south line 98 miles long. To simulate 20 bursts at each silo group, the computed single-burst dose rate at each silo group was multiplied by 20. The superpositioning method, then, was accomplished by stepping from point-to-point on the grid and calculating and adding the contribution of dose rate from each silo group to that point.

Machine limitations dictated the coarseness of the grid. Consequently, there was a reduction in accuracy. A summation of all grid points did not total up to the entire activity produced by the detonations; approximately five percent of the activity was missing. This missing activity was not deemed important to the comparisons, and is believed to be the result of the coarse grid at the extreme downwind limits of the fallout field.

Description of Multiburst Procedure

Results using the new model were obtained using the multiburst code shown in Appendix A. The required inputs were inserted, and the coordinates for the desired contours produced. No machine limitations were encountered using this model.

Comparison of Multiburst to Superposition

The comparison was made using the same inputs: 300 one-megaton bursts, each with 50 percent of its yield from fission; wind of 270/20 with a shear of one hr^{-1}; field width of 98 miles. The contours obtained were for doses of 100, 500, and 1000 r/hr.

Two different sets of contours were drawn for two different particle size-activity distribution curves. The WSEG contours use a size-activity curve with parameters of $\alpha = 44$ and $\ell n\beta = .690$. A second set of contours was generated using size-activity curve parameters of $\alpha = 37$ and $\ell n\beta = 1.528$. These parameters more closely resemble those used by the DELFIC model (see Figure 3). All calculations using these parameters and the Bridgman/Bigelow procedure for activity deposition rate (Ref 2:29-30) will be termed AFIT calculations.

Figures 4a through 4c show the three desired contour comparisons using the WSEG formulation for activity deposition rate, while Figures 5a through 5c show the same

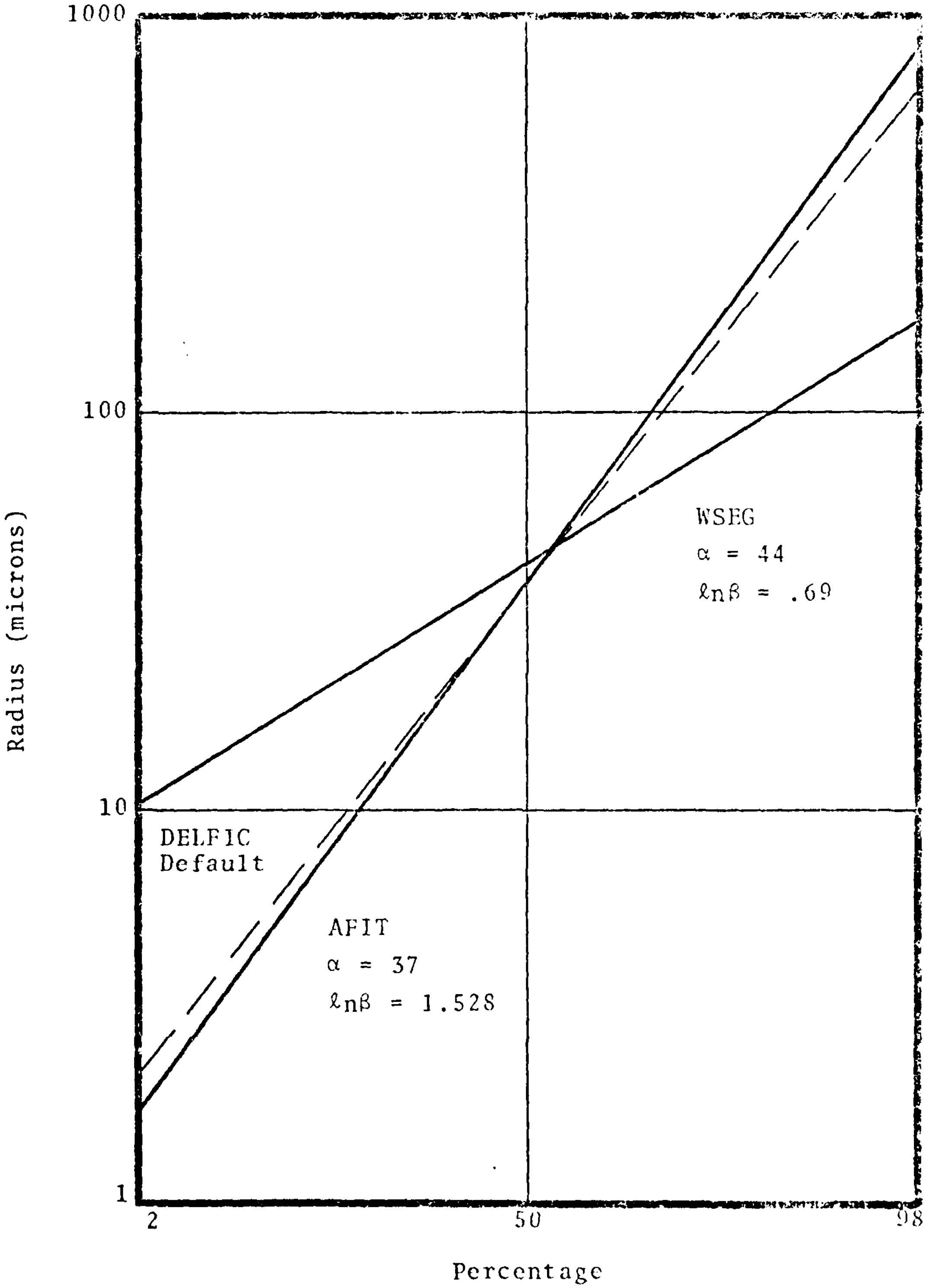


Figure 3. Cumulative Activity-Size Distribution Curves

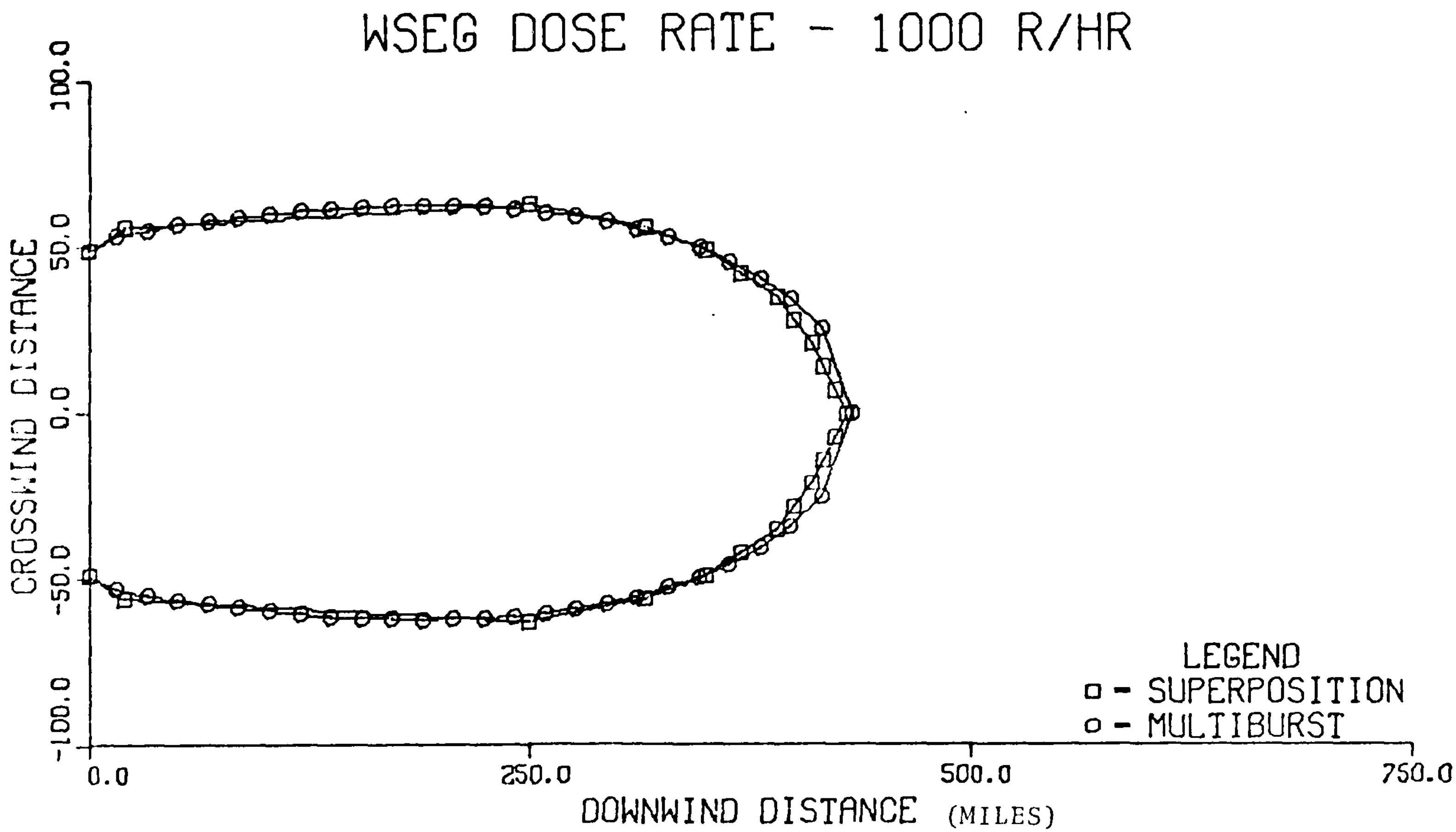


Figure 4a. WSEG Comparison

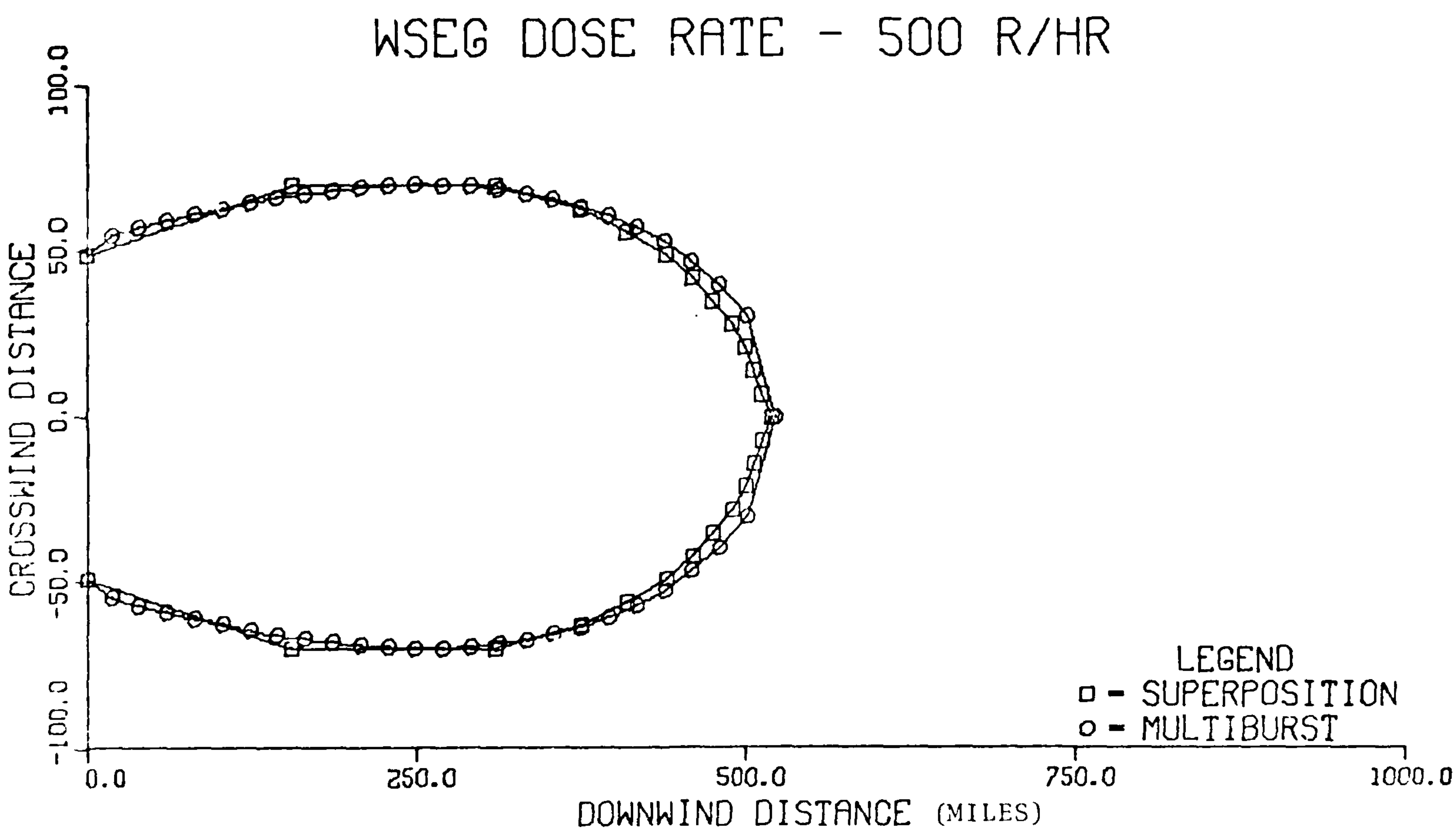


Figure 4b. WSEG Comparison

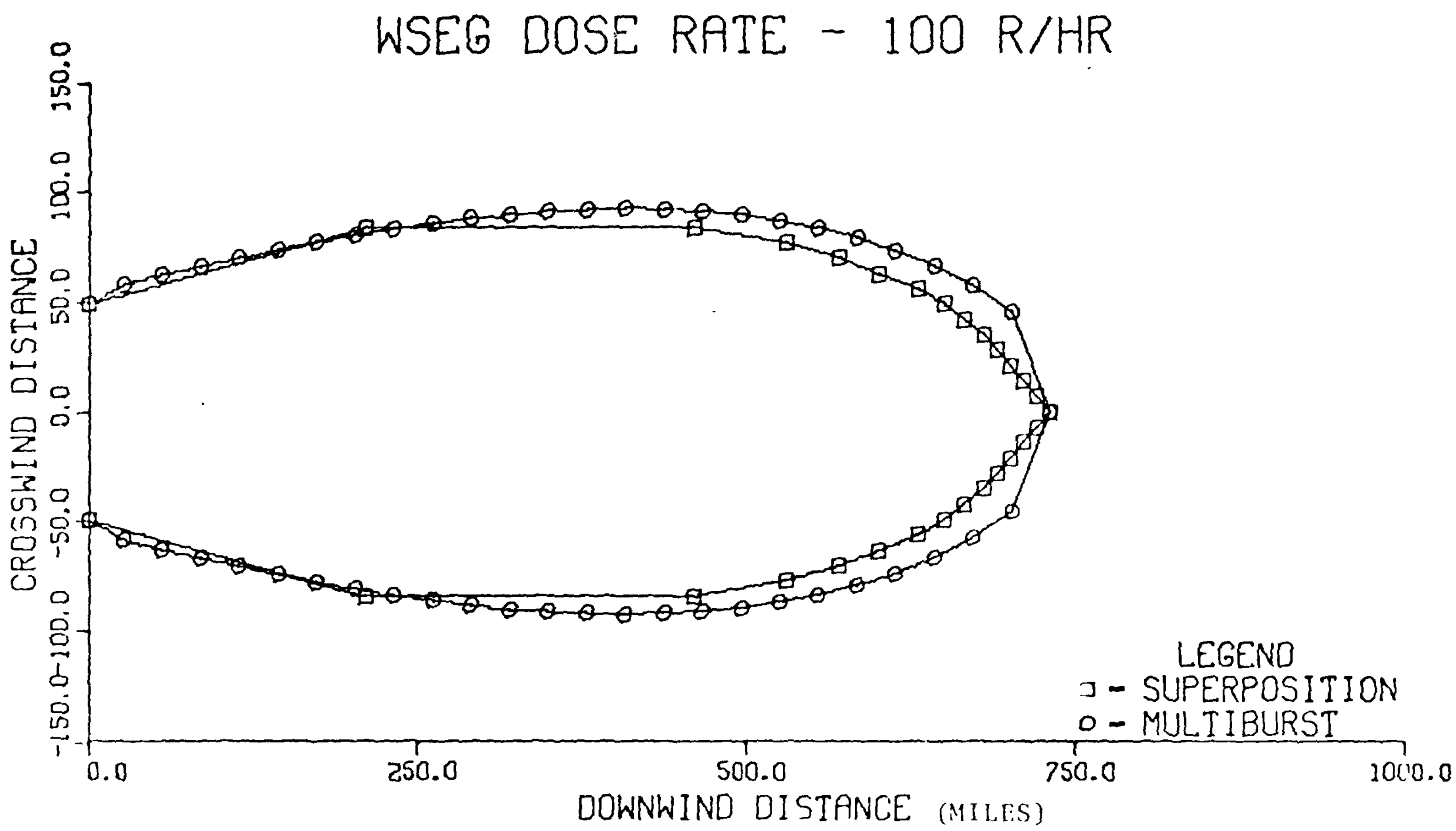


Figure 4c. WSEG Comparison

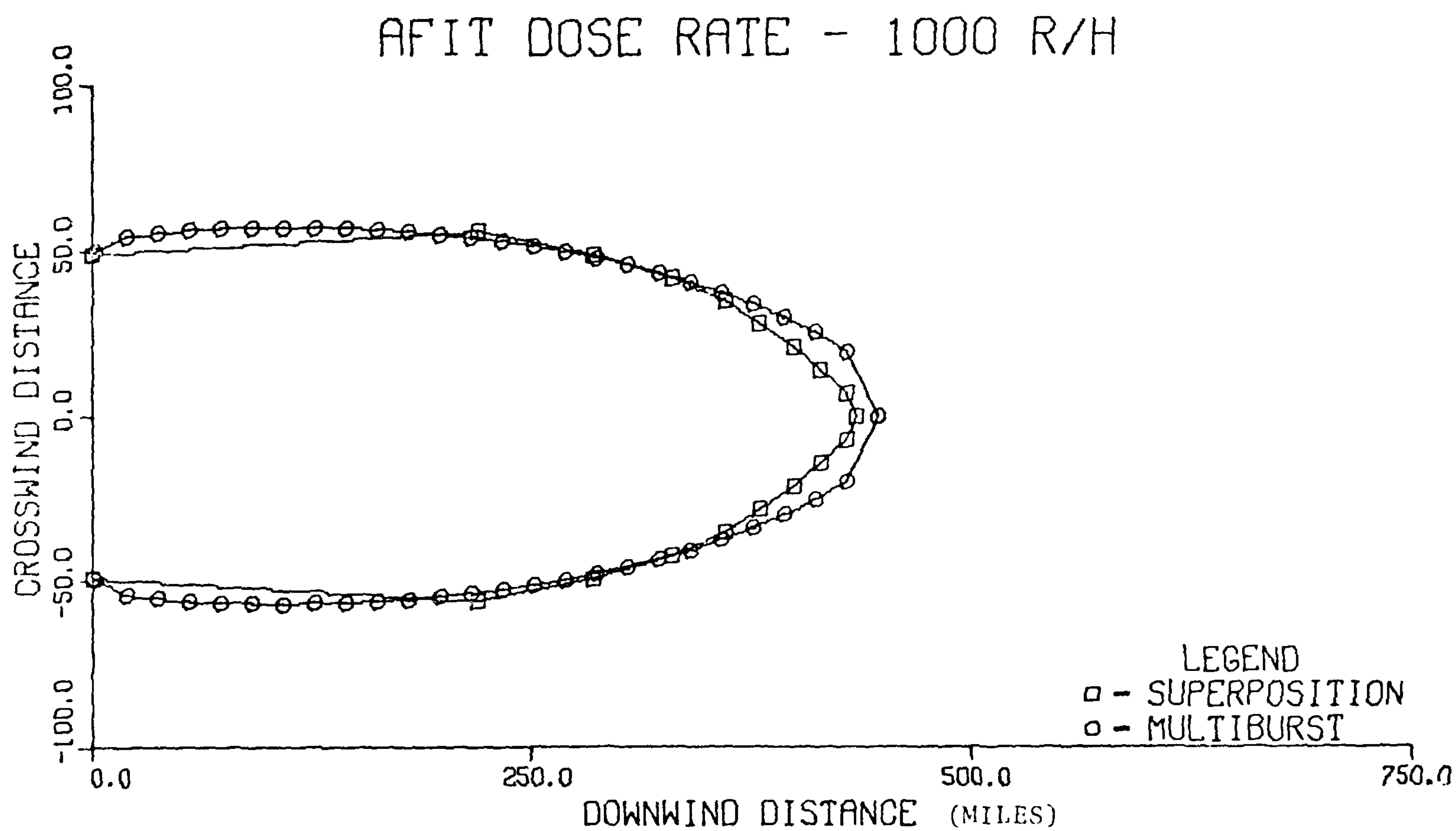


Figure 5a. AFIT Comparison

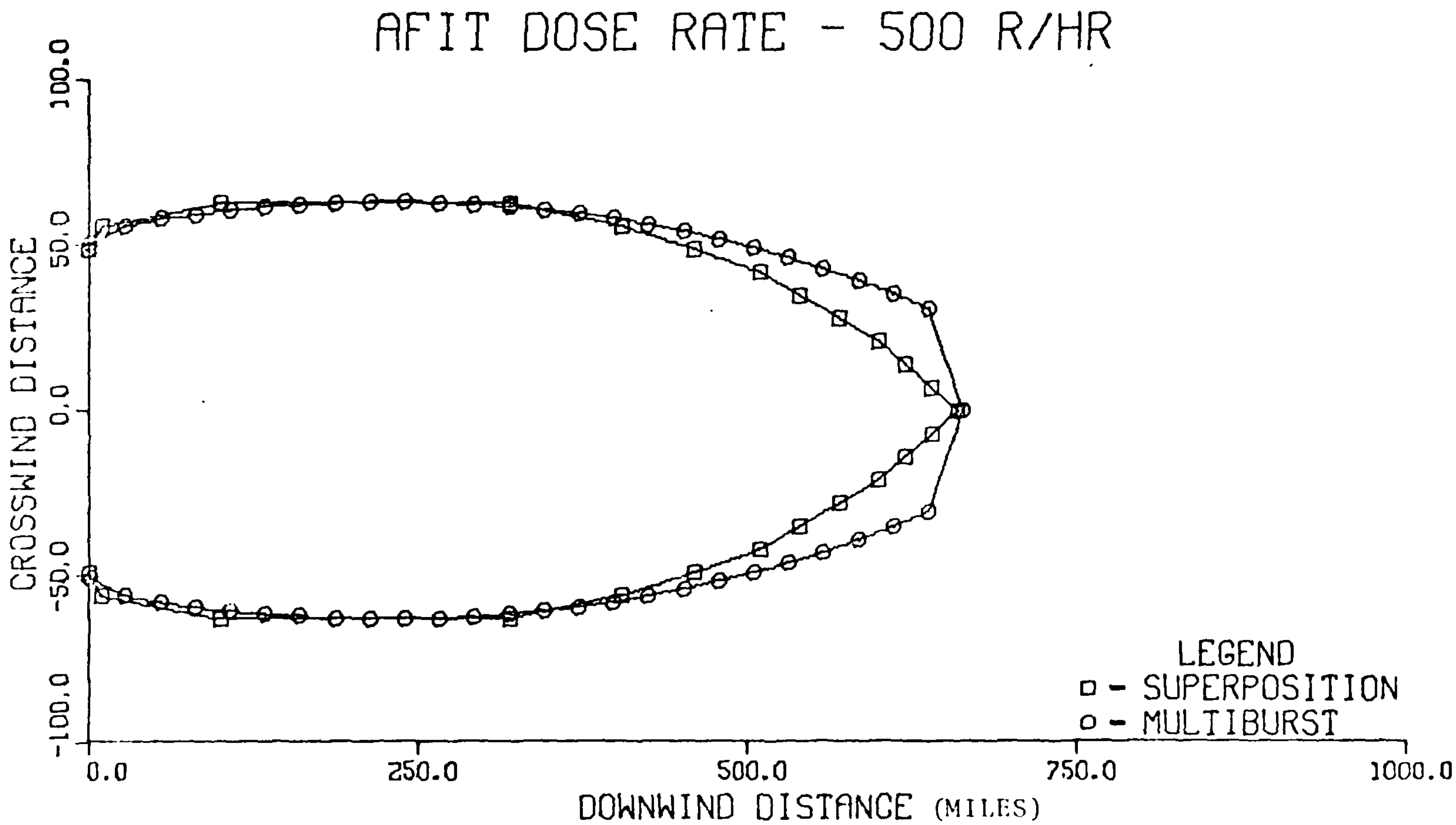


Figure 5b. AFIT Comparison

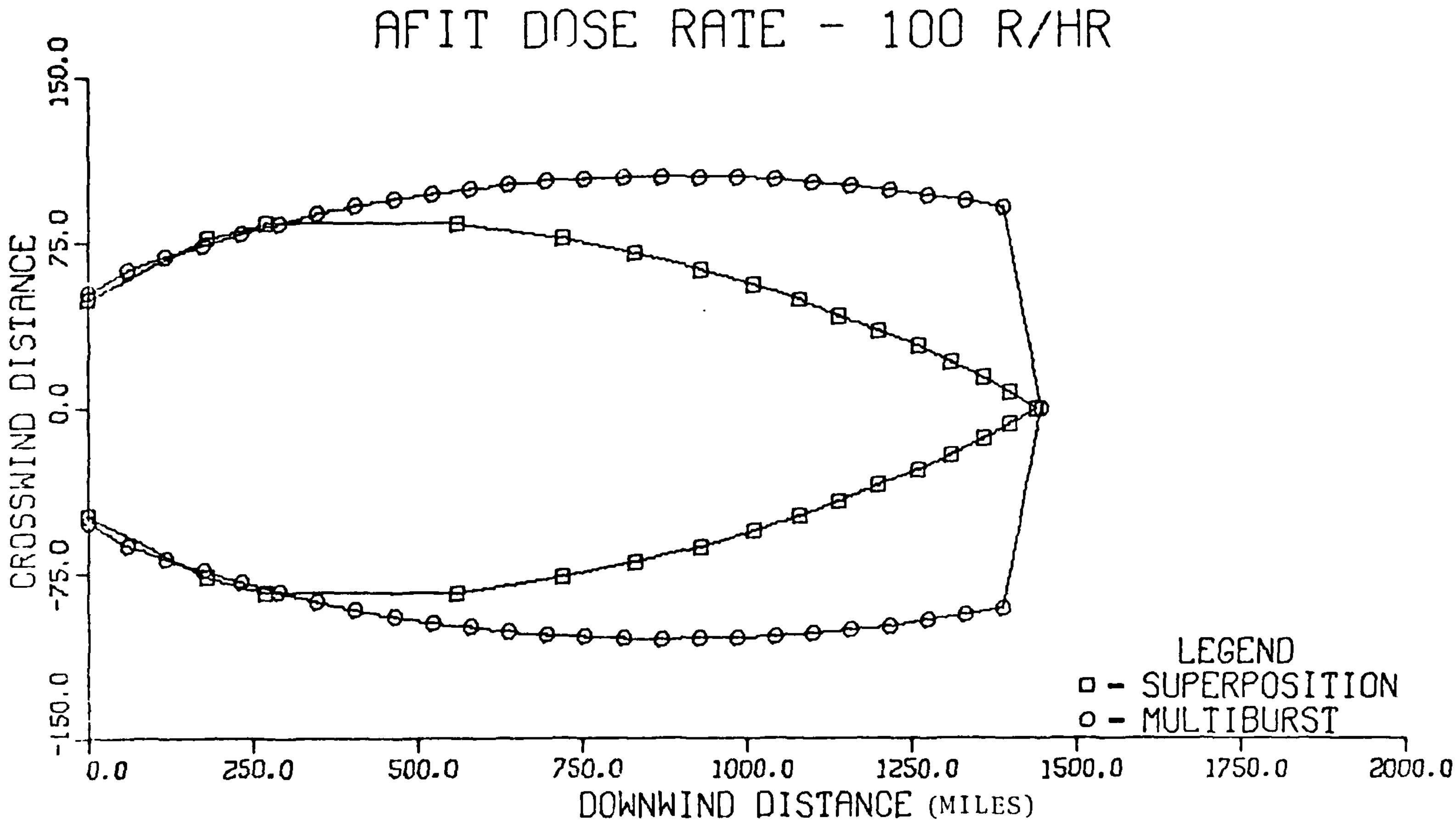


Figure 5c. AFIT Comparison

comparison using the AFIT activity deposition formulation. As can be seen, these comparisons of superpositioning and the multiburst code are in good agreement. For the smaller dose rates there is a difference in the crosswind deposition of activity as downwind distance increases from ground zero. This discrepancy is due to the way the 300 bursts are distributed in the superpositioning procedure; that is, the 15 groups of 20 detonations more closely resemble fifteen 20-megaton detonations. This aggregate cloud will taper off much more than an aggregate cloud of 300 one-megaton bursts, as shown by Figure 5c. Consequently, the multiburst contours are considered to be more accurate.

IV. Employment of the Multiburst Code

To demonstrate the ease with which this new model can be used, the fallout patterns from a counterforce attack on an MX field were generated. Several different scenarios were devised, and the appropriate inputs made to the code MULTI, which is listed in Appendix A. MULTI incorporates the multiburst $f(y,t)$ distribution developed in Chapter II. An interesting feature of this code is the ability to use either the WSEG $g(t)$ (activity deposition rate) or the AFIT $g(t)$ in dose/dose rate computations. Therefore, for all scenarios, a comparison study was made of contours generated using the two different $g(t)$'s.

Scenarios

The MX field, consisting of 4600 shelters, is proposed to be situated in the states of Utah and Nevada. Several different scenarios were created around these shelters, based on several parameters. These parameters include the number of attacking reentry vehicles (RV), the yield and fission fraction of each RV, and the average continental winds. Two different dose contours were generated for each dose using the two different $g(t)$'s. Based on all these variables, a total of 64 plots (or 32 comparisons) were created.

To simulate a full, counterforce attack, 4600 RV's were targeted against the MX field. The crosswind width of this field was estimated at 190 miles. The yield of each RV was allowed to be one of two values: either one megaton or 500 kilotons. These yields are commensurate with the warhead yields of Soviet ICBM's. A 50 percent yield due to fission was assumed for each warhead. As another comparison, the number of RV's was decreased to 2300 with warhead yields remaining the same.

Several average winds were obtained (Ref 8) for the continental United States as a whole at an altitude of 40,000 feet. All winds were from the west (270°) and had different velocities based on the season. An average summer wind had a velocity of 35 miles per hour (or written as 270/35), while an average winter wind was given as 270/77. Strong seasonal winds were derived by adding one standard deviation to the average winds. This resulted in a strong summer wind of 270/70 and a strong winter wind of 270/119. These winds were then applied to each scenario.

Two different dose contours were generated for each scenario, the doses being 1500 and 500 rems. Since most single story residences above ground have a protection factor of three (Ref 7:33), the 1500 rem contour represents 500 rems indoors. Five hundred rems is considered to be the dosage necessary to produce 50 percent fatalities in 30 days (Ref 7:32).

Fatalities will not be estimated in the following comparisons. However, the contour lines do enclose the areas of high fatalities from fallout. Major cities downwind from the bursts are delineated on the figures for easier reference. It will be obvious that the WSEG formulation significantly underestimates these areas of high fatalities.

Results

Sixty-four computer runs were made interactively using a CDC 6600 computer. Average compilation time was 1.8 seconds with average execution time of 1.5 seconds. The 64 runs were then combined into 32 comparative graphs.

These 32 figures were arranged in four groups according to wind velocity. Figures 6a through 6h have a common wind of 270/35 (average summer). The second group, Figures 7a through 7h, has a wind of 270/77 (average winter), while Figures 8a through 8h have a slightly lower wind of 270/70 (strong summer). The strong winter wind group, Figures 9a through 9h, is last with a wind of 270/119. All winds have a shear of 1/hr.

It is obvious from all comparisons that the WSEG contour lines encompass much less area than the AFIT contour lines. This is a direct result of the Bridgman/Bigelow method of computing $g(t)$ and of the parameters used for

the particle size-activity distribution curve. Colarco showed the same kind of result, only for a single-burst model.

It is interesting to note that the WSEG contours are probably close approximations to the contours generated by the Department of Defense (DoD) in their predictions of fatalities from an MX field attack; the same basic WSEG formulation is used. Consequently, the estimation of resulting fatalities is not as high as it would be if the AFIT contours were used, especially in the low wind situations. As the wind increases and the WSEG contours finally stretch into the Atlantic Ocean, the number of fatalities predicted by WSEG and AFIT will be about the same as the enclosed population is equal.

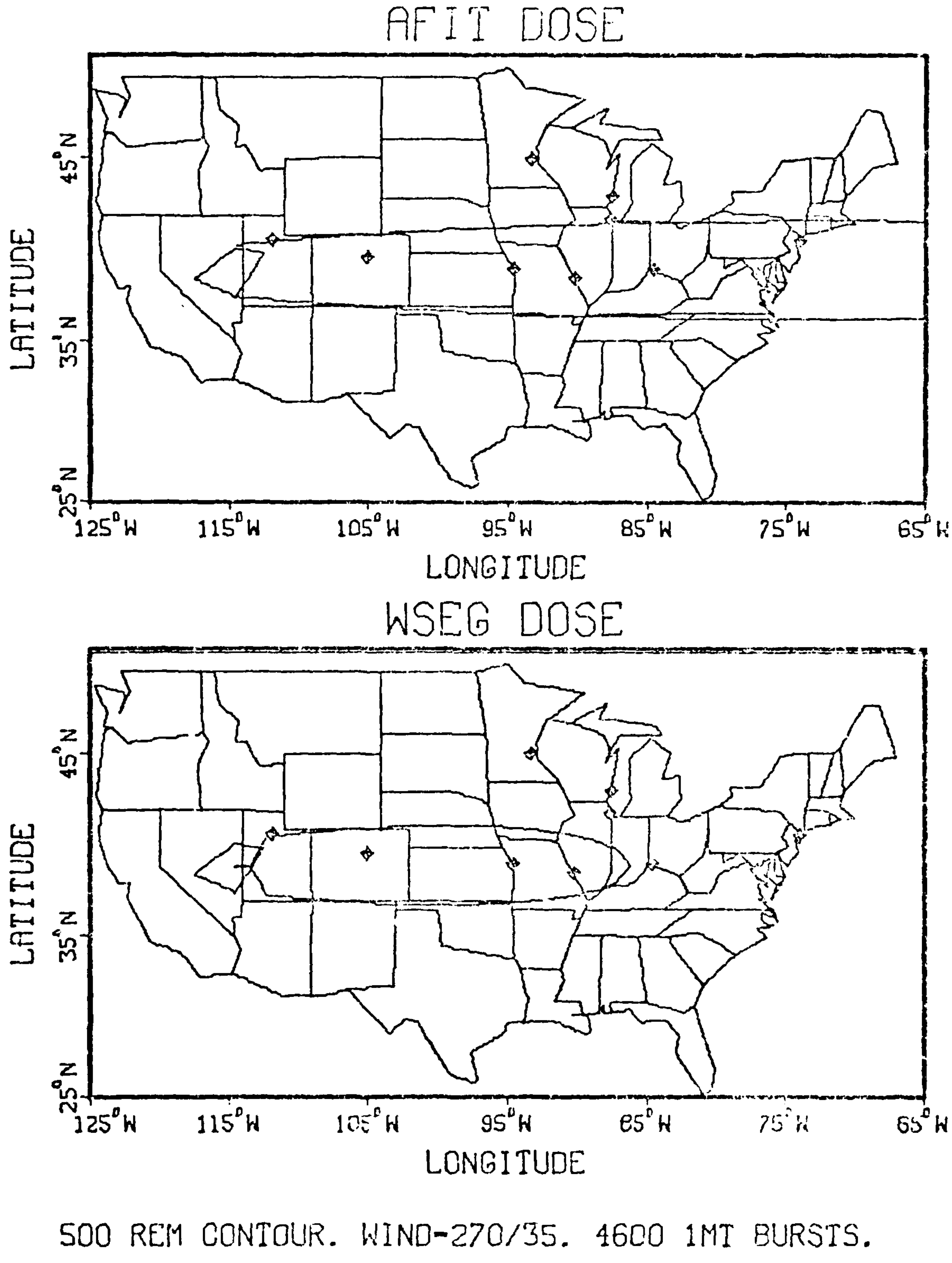
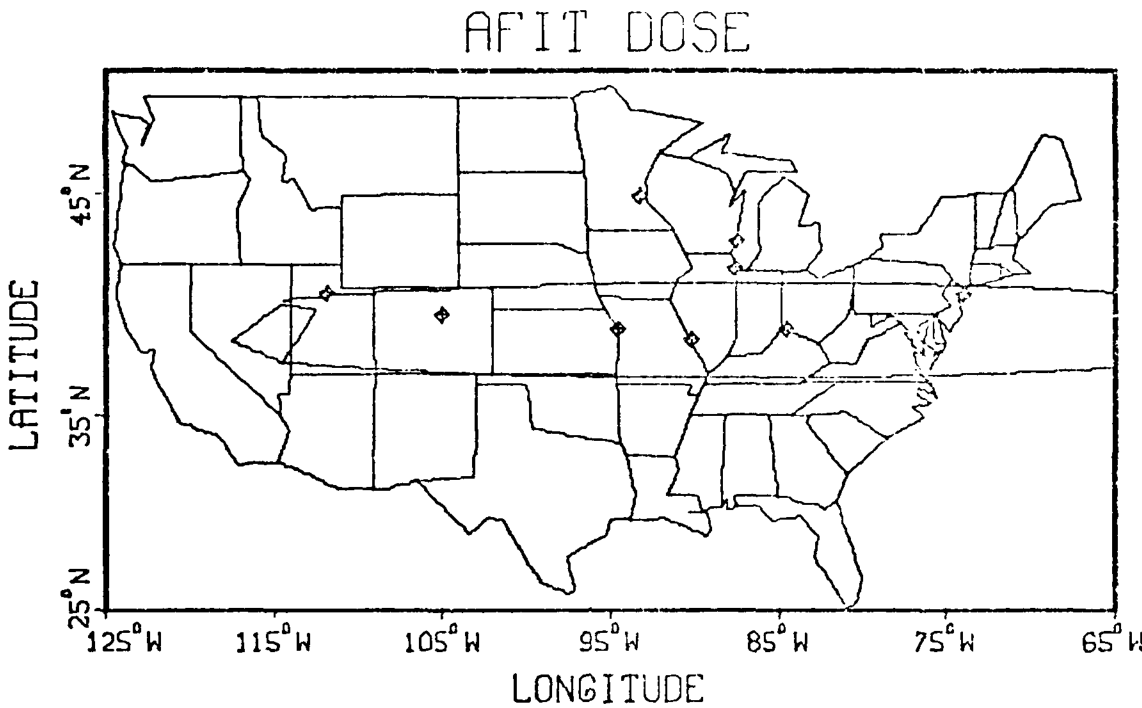
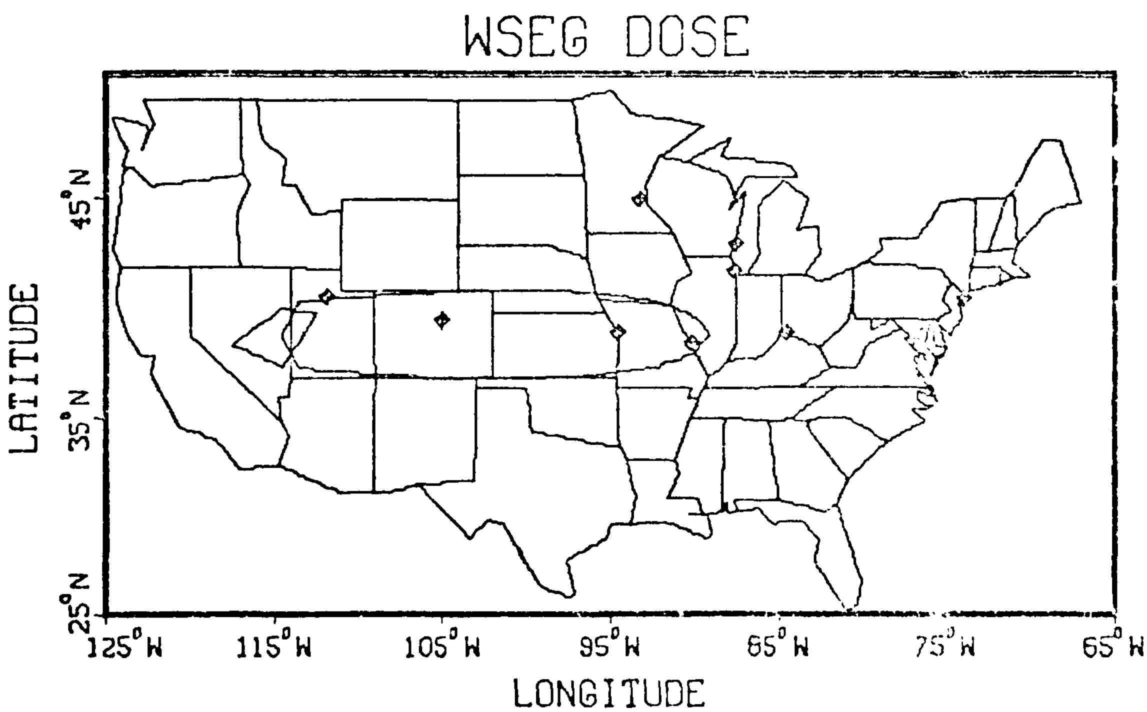


Figure 6a. Average Summer Wind Contours





500 REM CONTOUR. WIND-270/35. 2300 1MT BURSTS.

Figure 6b. Average Summer Wind Contours

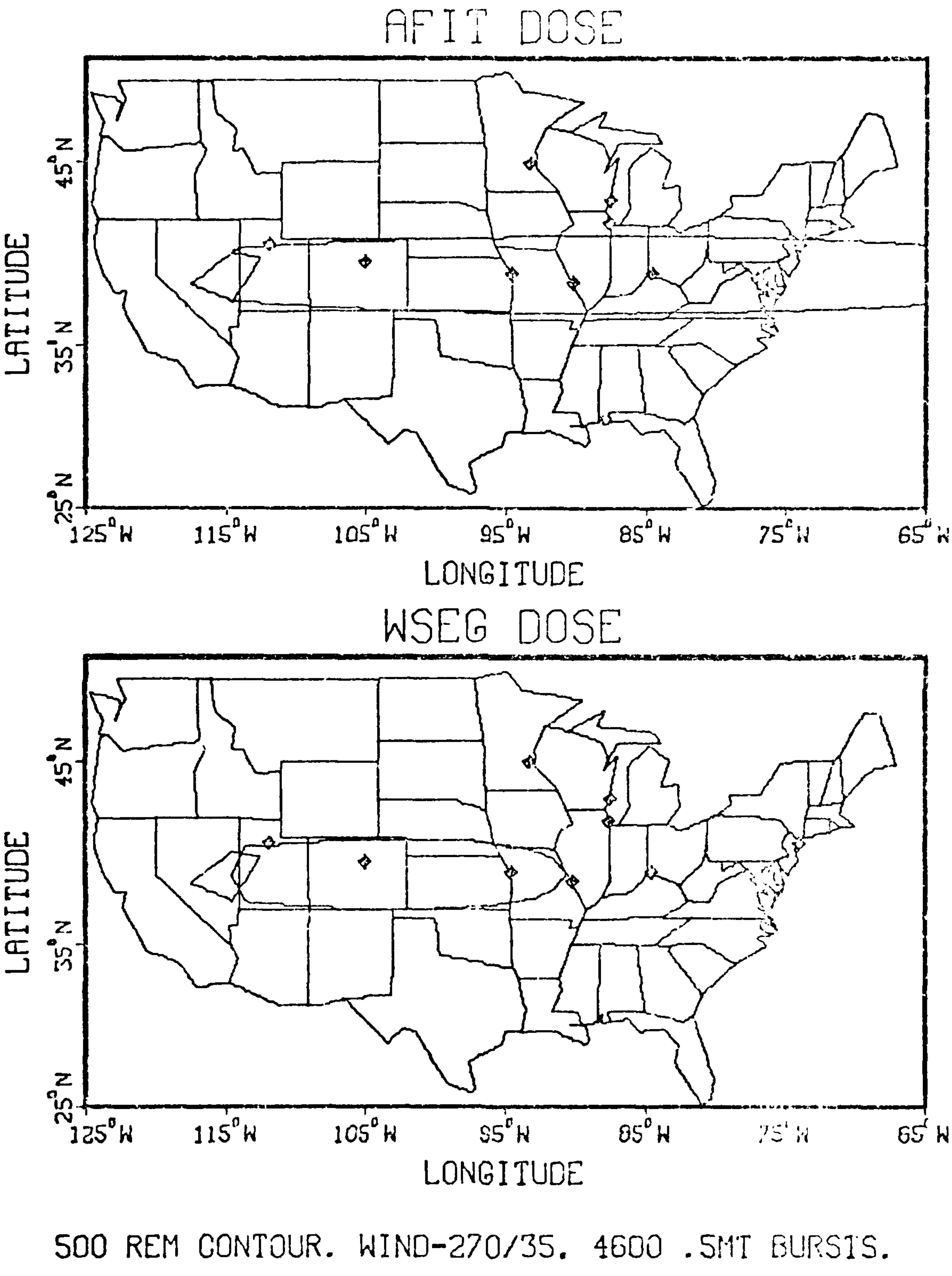
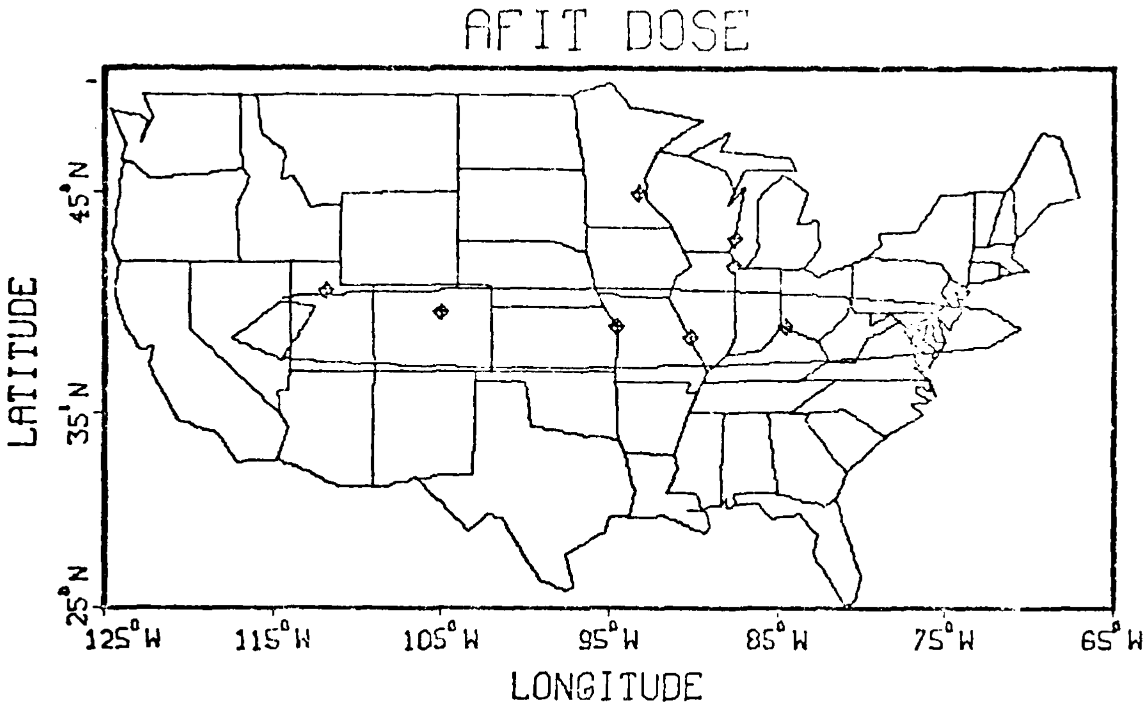
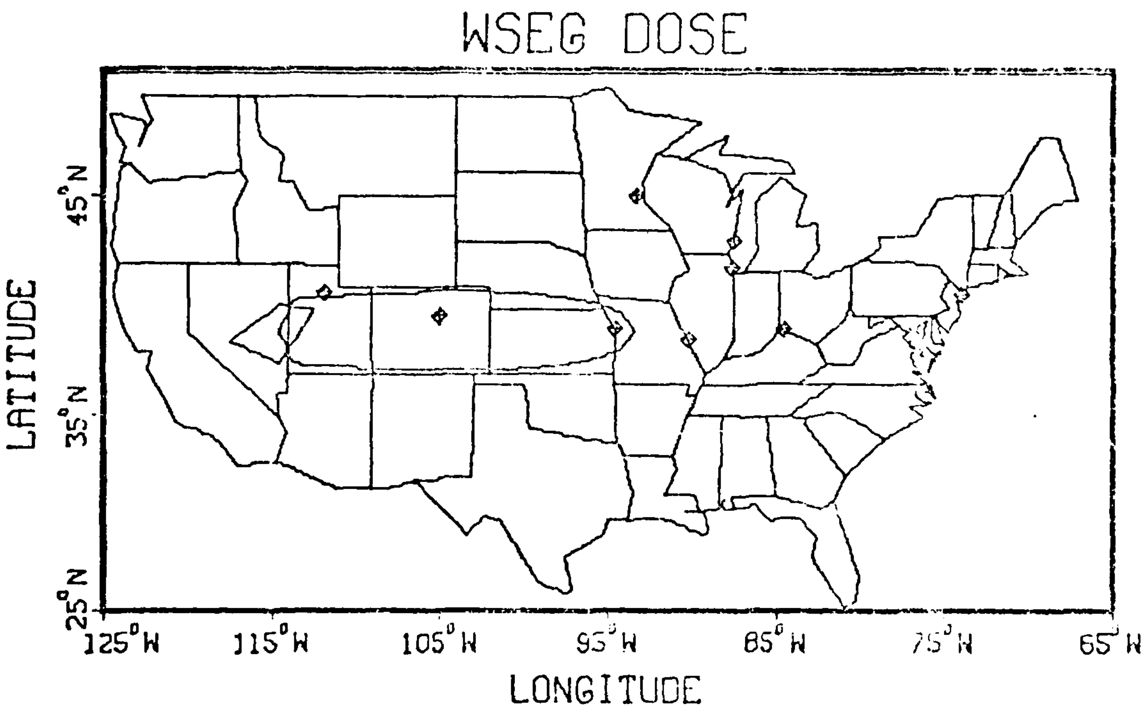


Figure 6c. Average Summer Wind Contours





500 REM CONTOUR. WIND-270/35. 2300 .5MT BURSTS.

Figure 6d. Average Summer Wind Contours

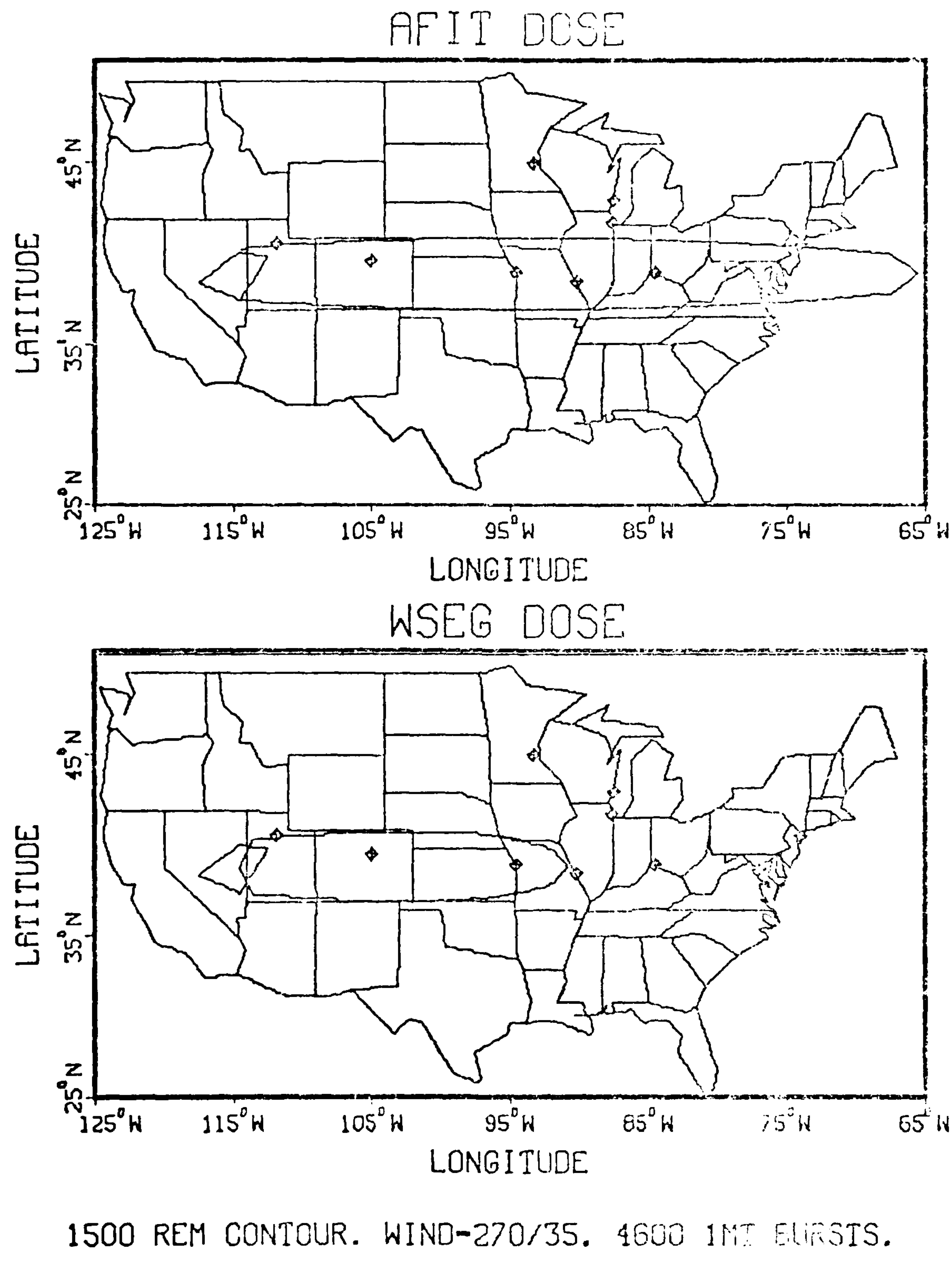
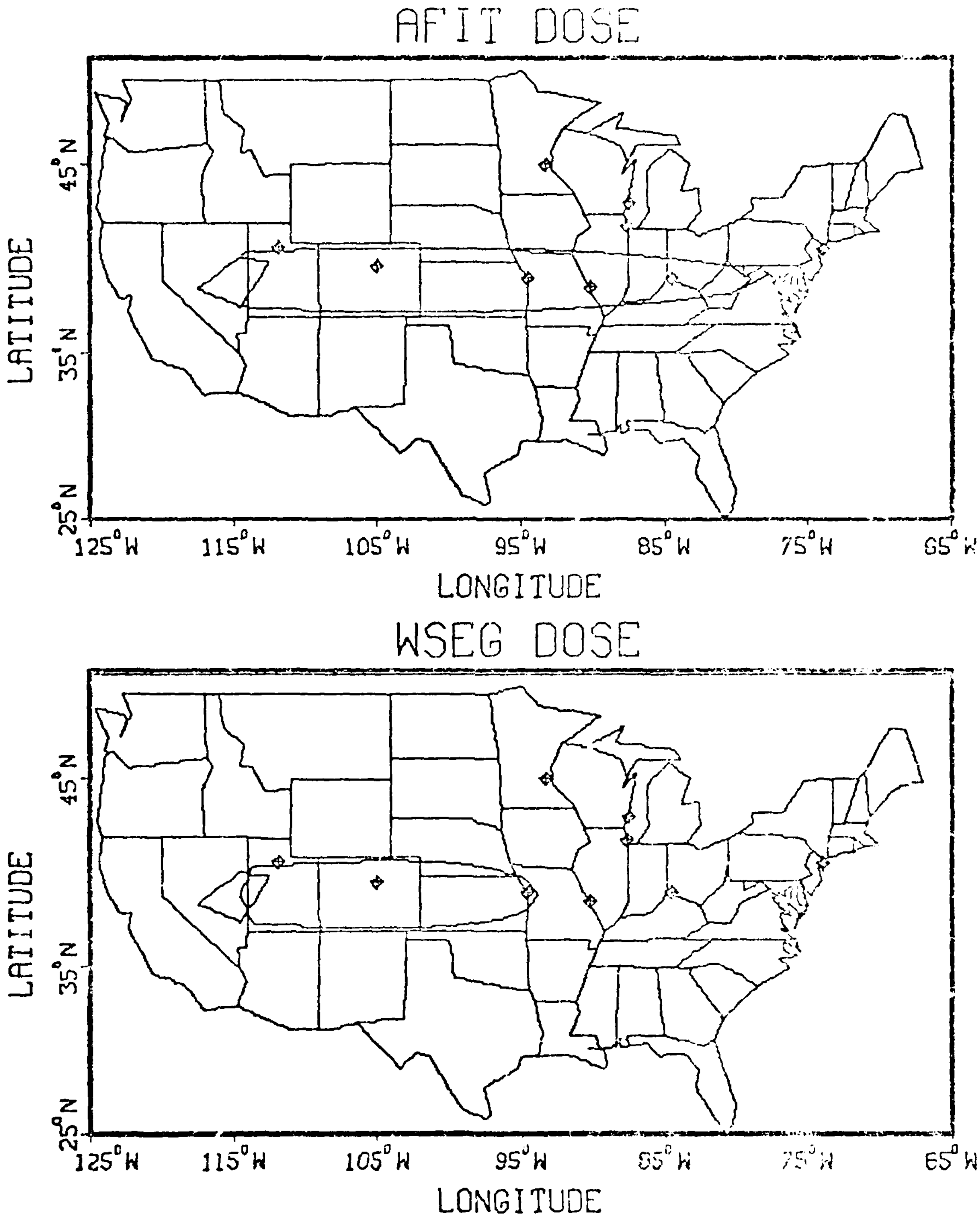
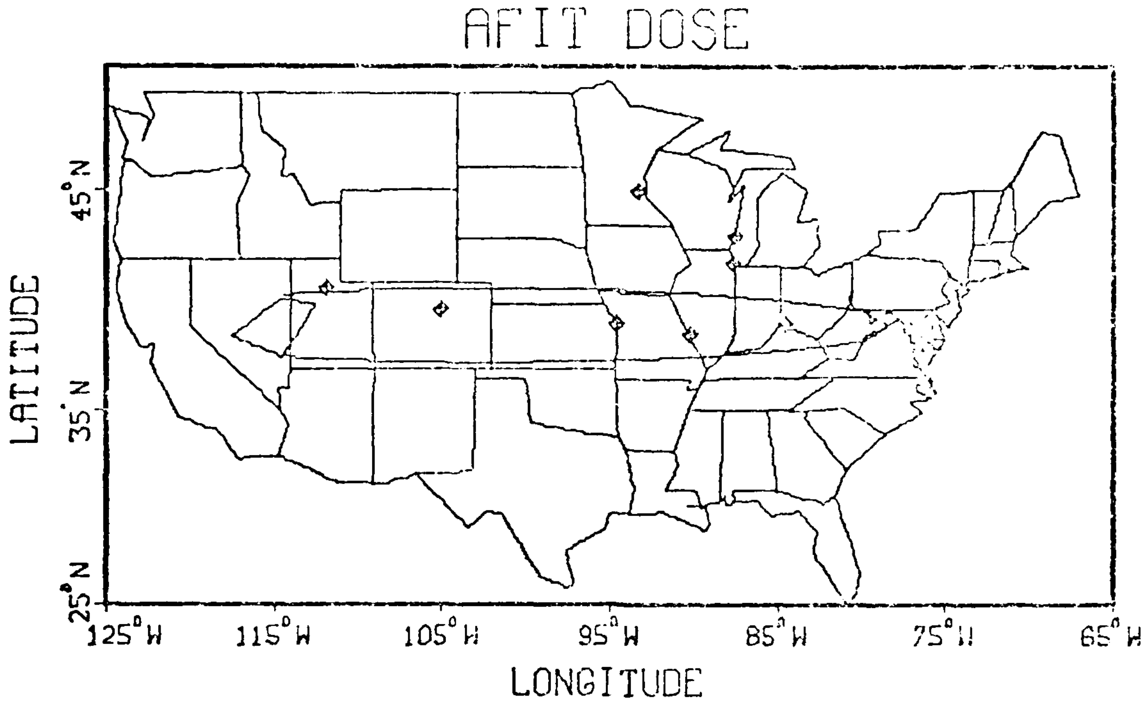


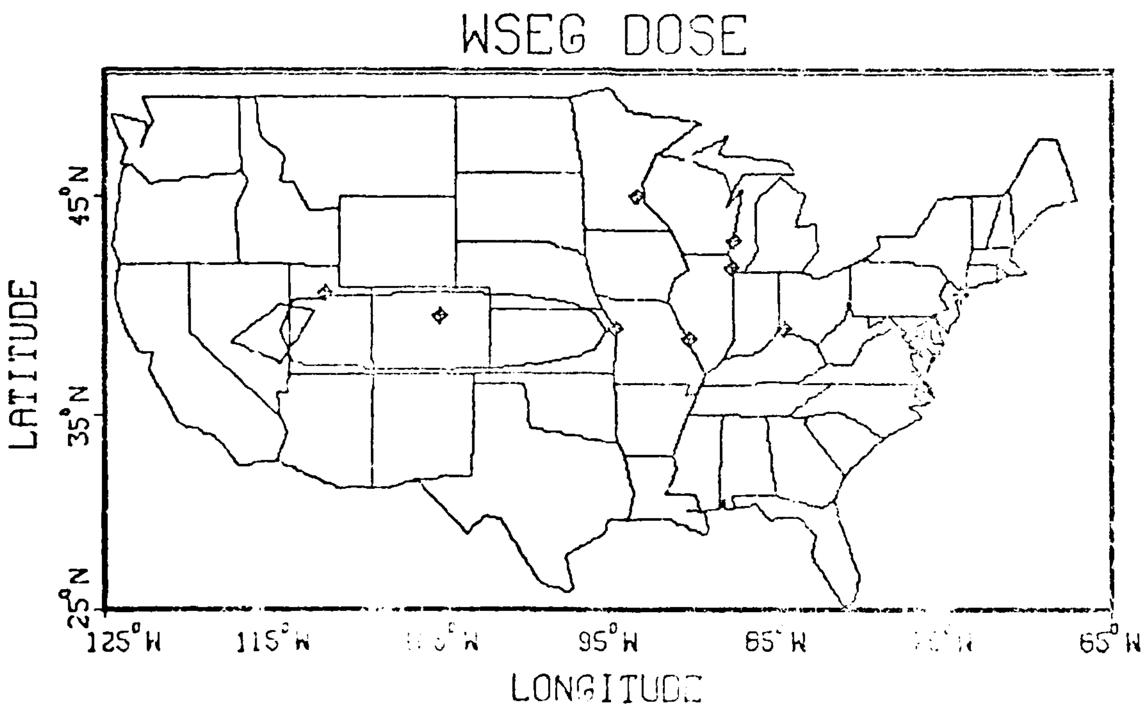
Figure 6e. Average Summer Wind Contours



1500 REM CONTOUR. WIND-270/35. 2300 1MT BURSTS.

Figure 6f. Average Summer Wind Contours





1500 R/M CONT R. WIND-270/35. 4600 .5MT BURSTS.

Figure . Average Summer Wind Contours

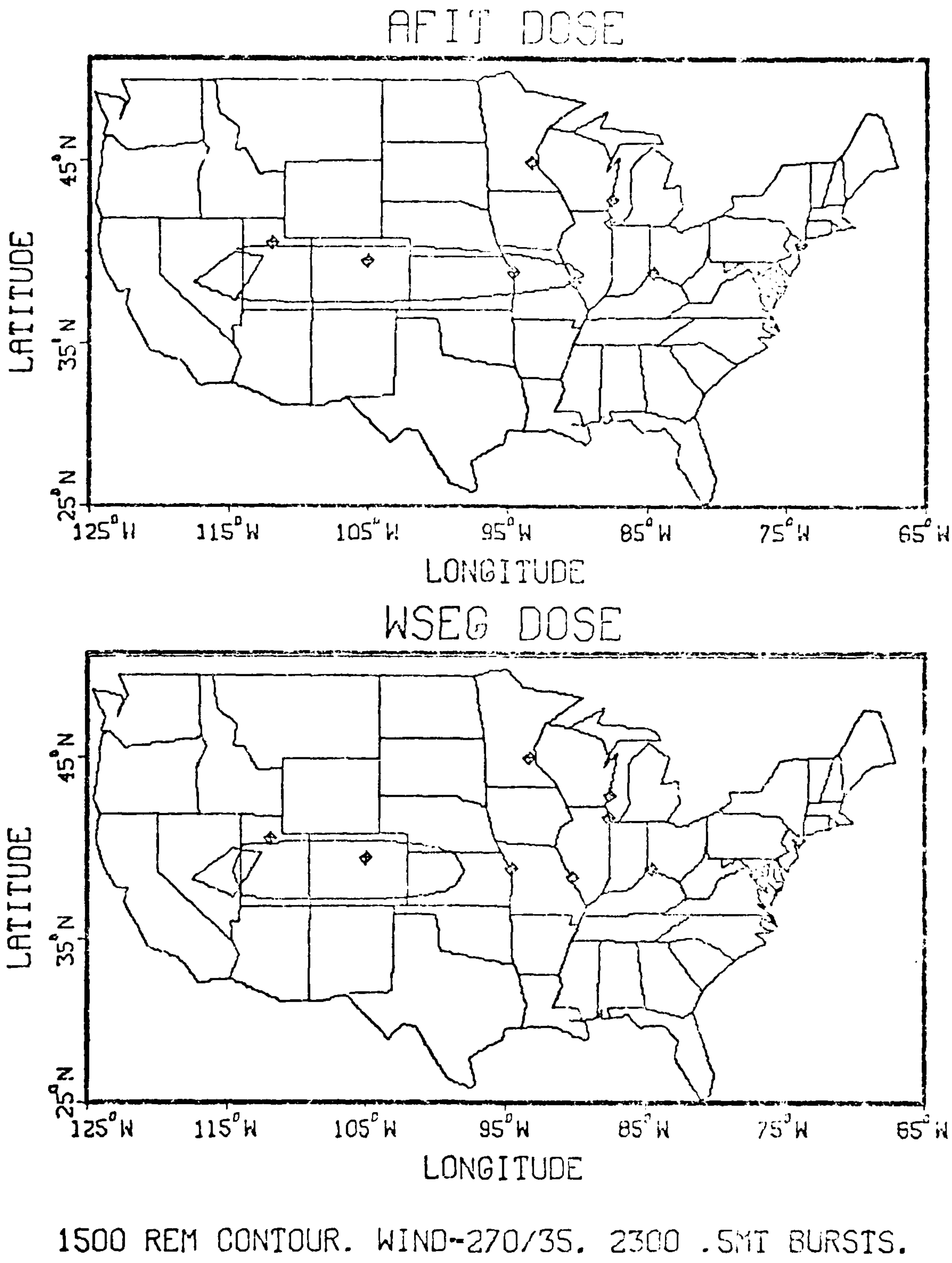


Figure 6h. Average Summer Wind Contours

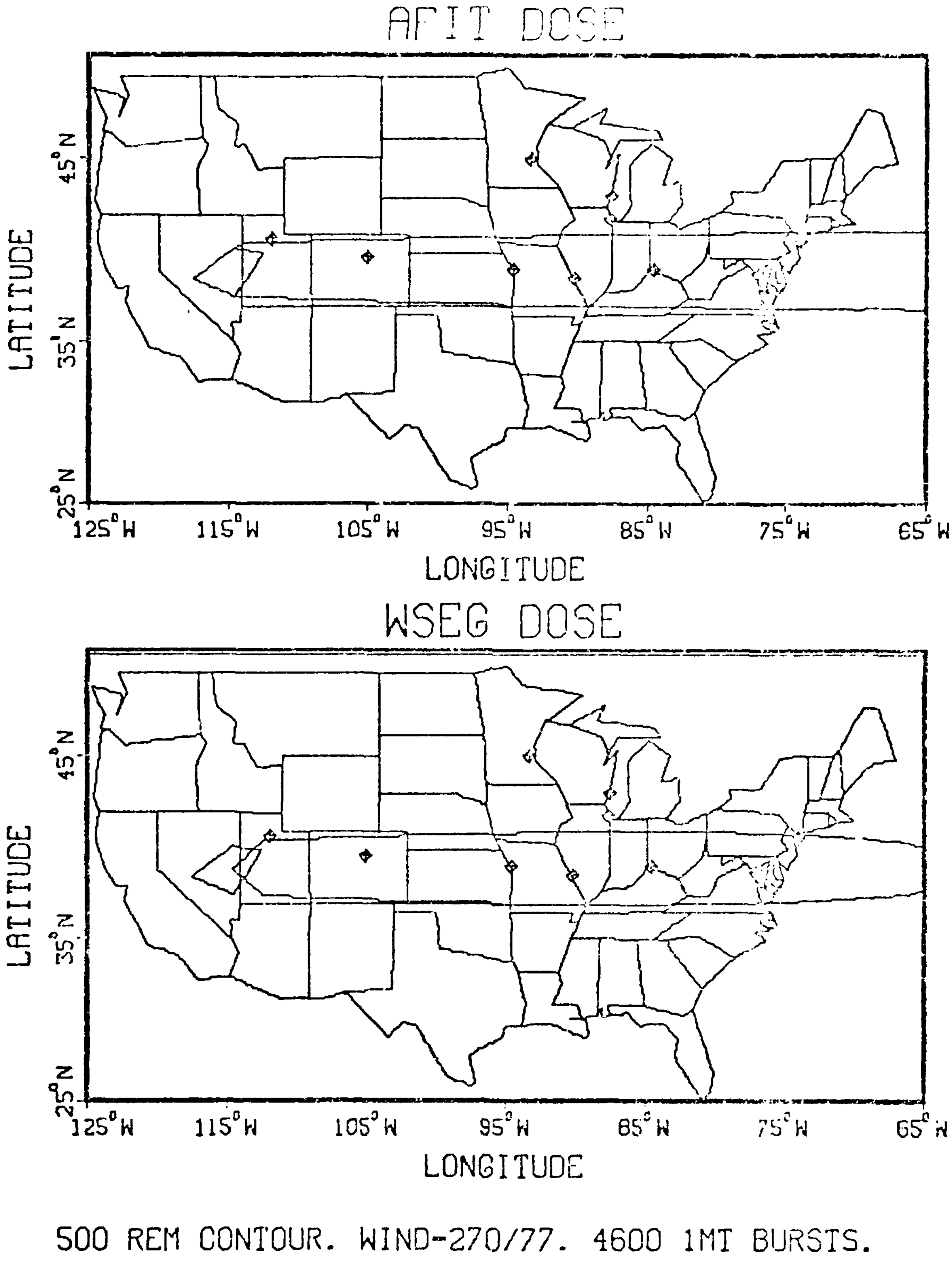
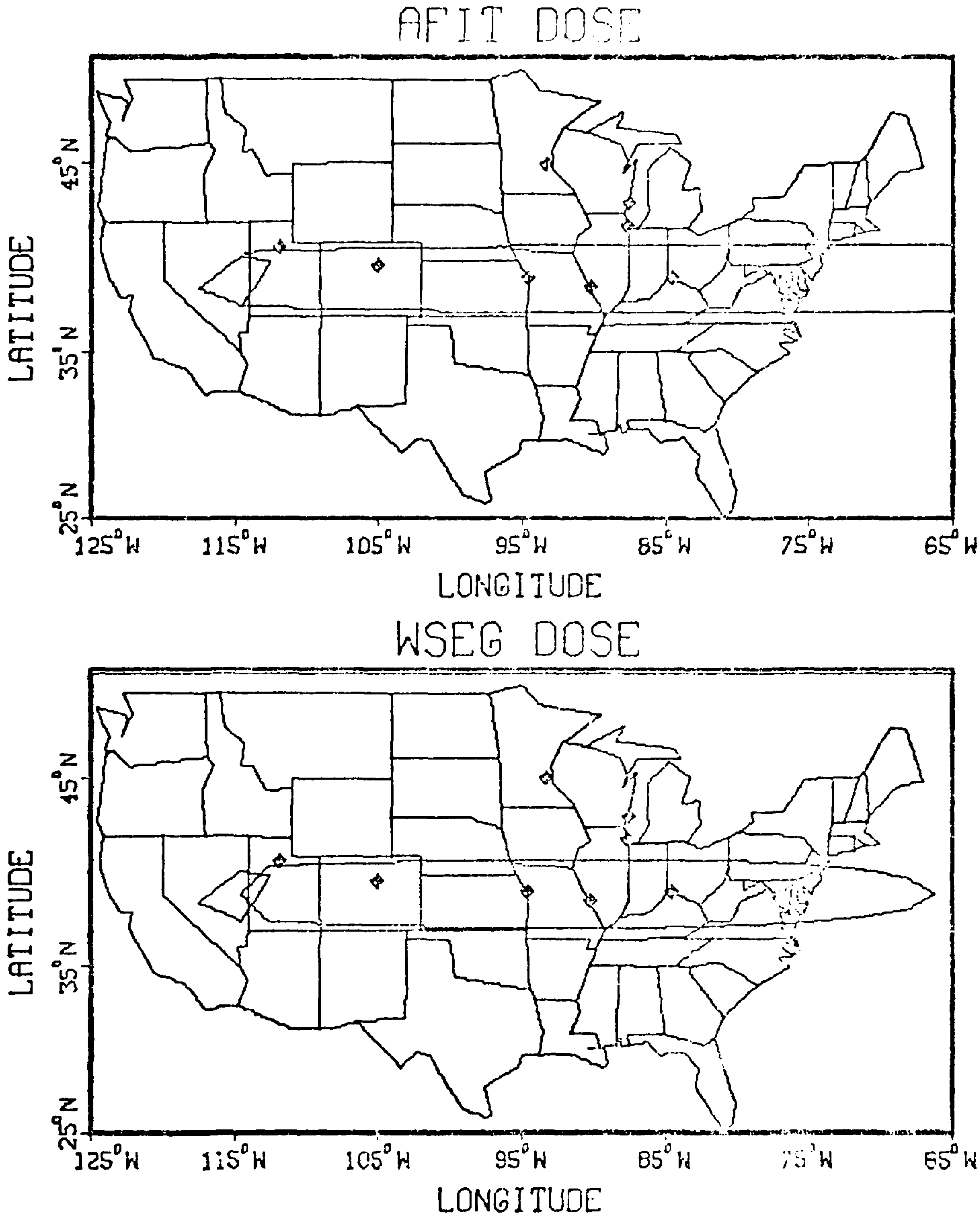
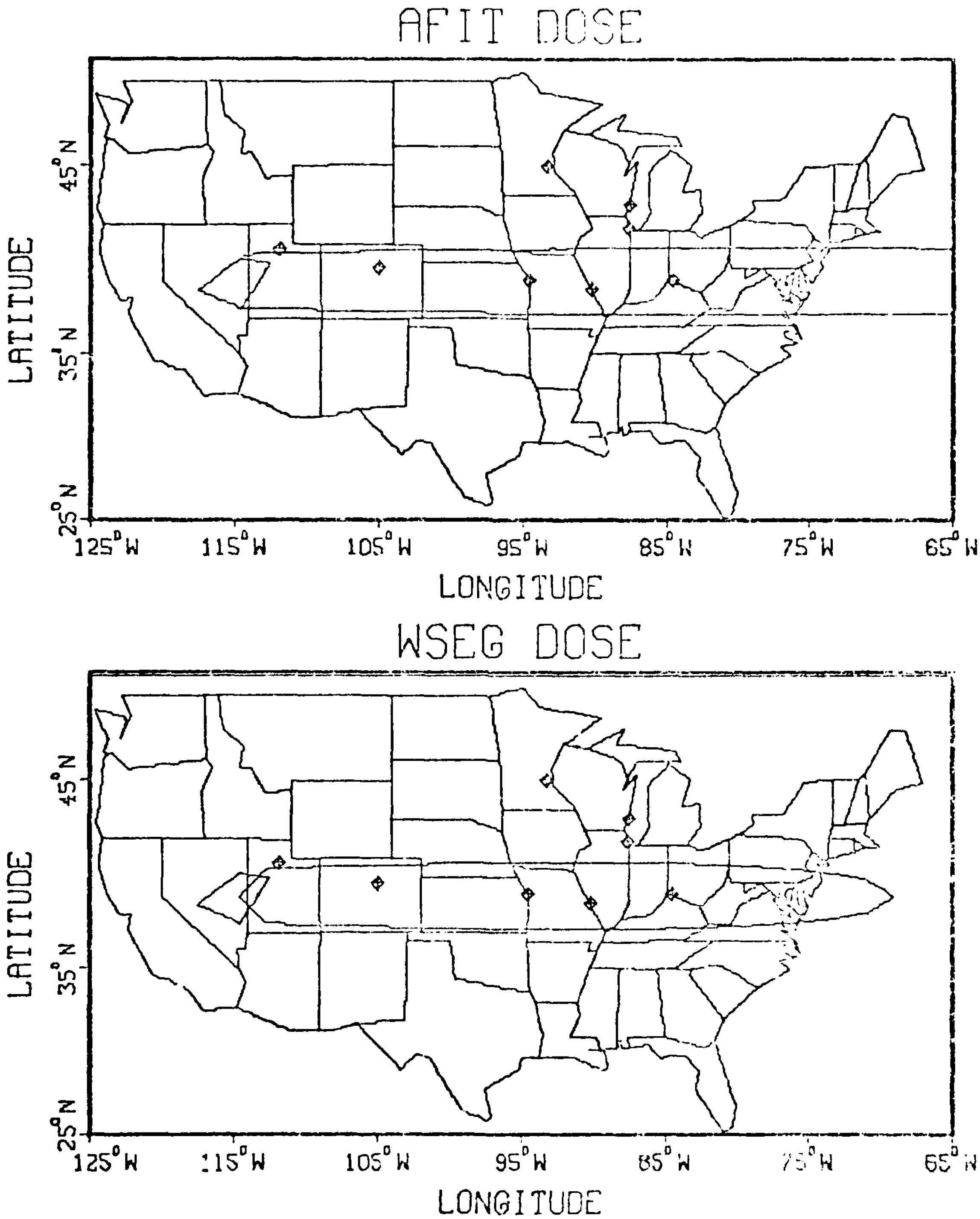


Figure 7a. Average Winter Wind Contours



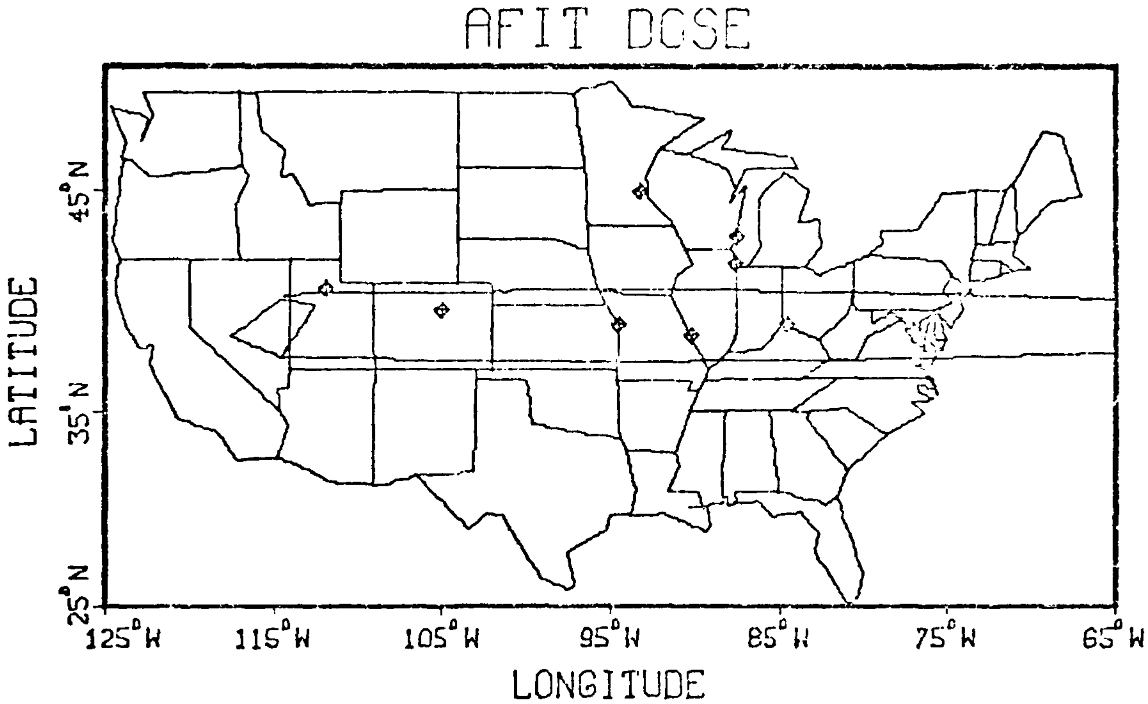
500 REM CONTOUR. WIND-270/77. 2300 1MT BURSTS.

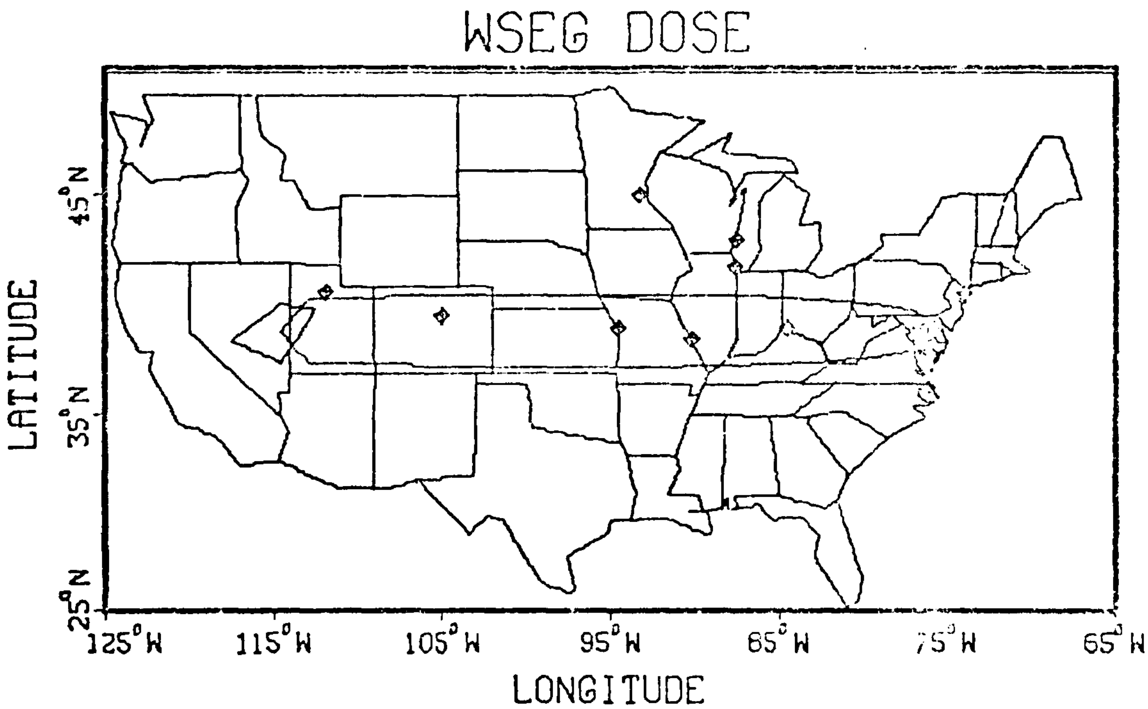
Figure 7b. Average Winter Wind Contours



500 REM CONTOUR. WIND-270/77. 4600 .5MT BURSTS.

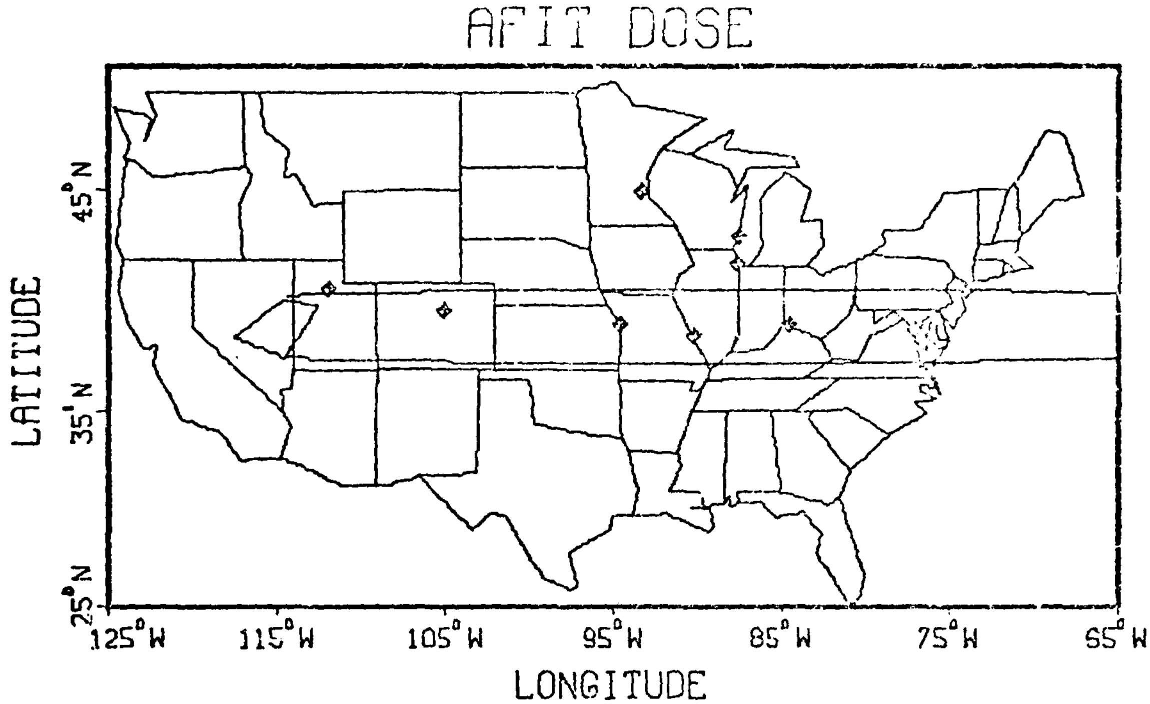
Figure 7c. Average Winter Wind Contours

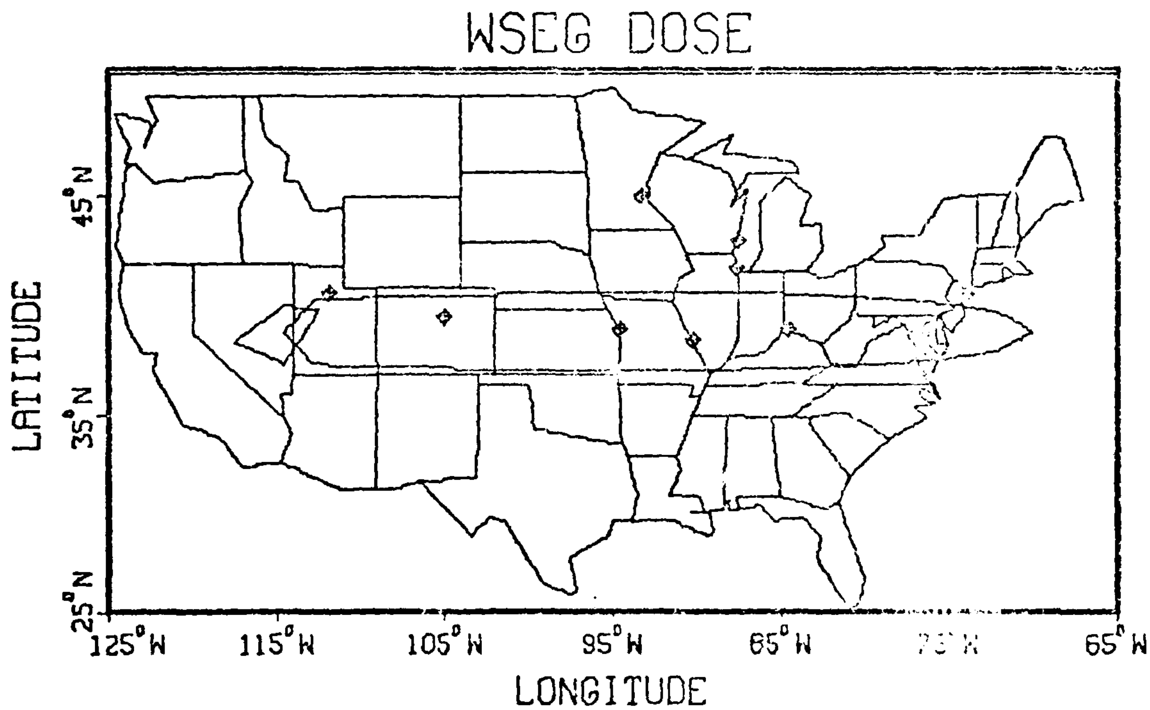




500 REM CONTOUR. WIND-270/77. 2300 .5MT BURSTS.

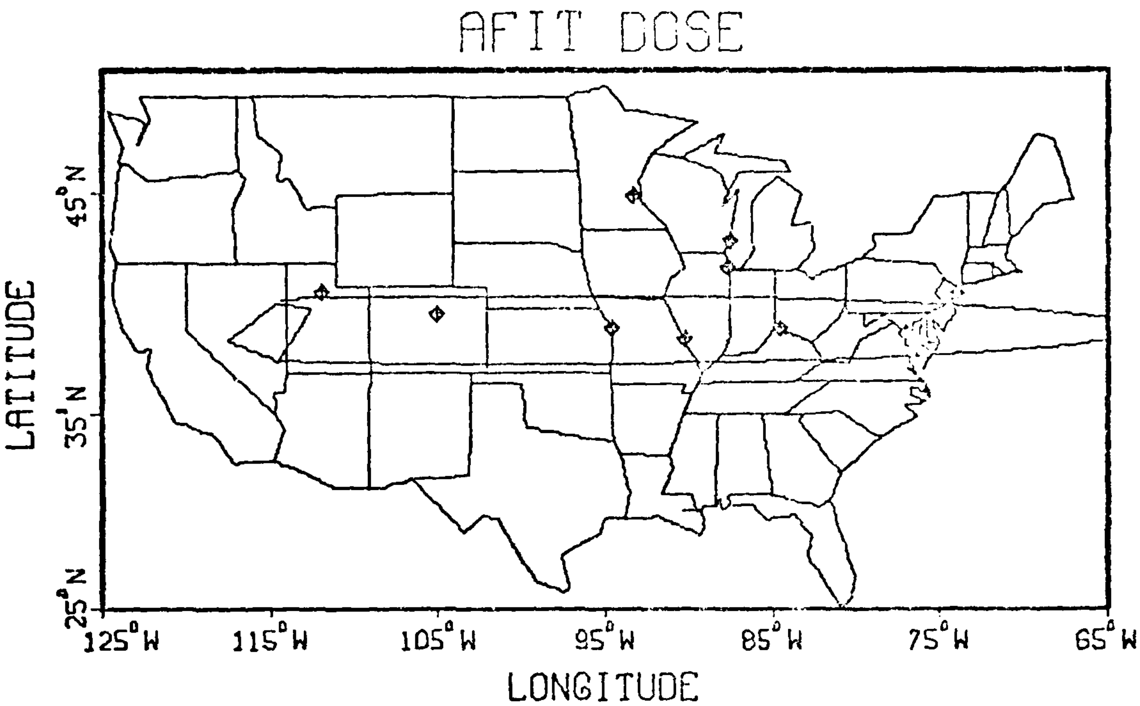
Figure 7d. Average Winter Wind Contours

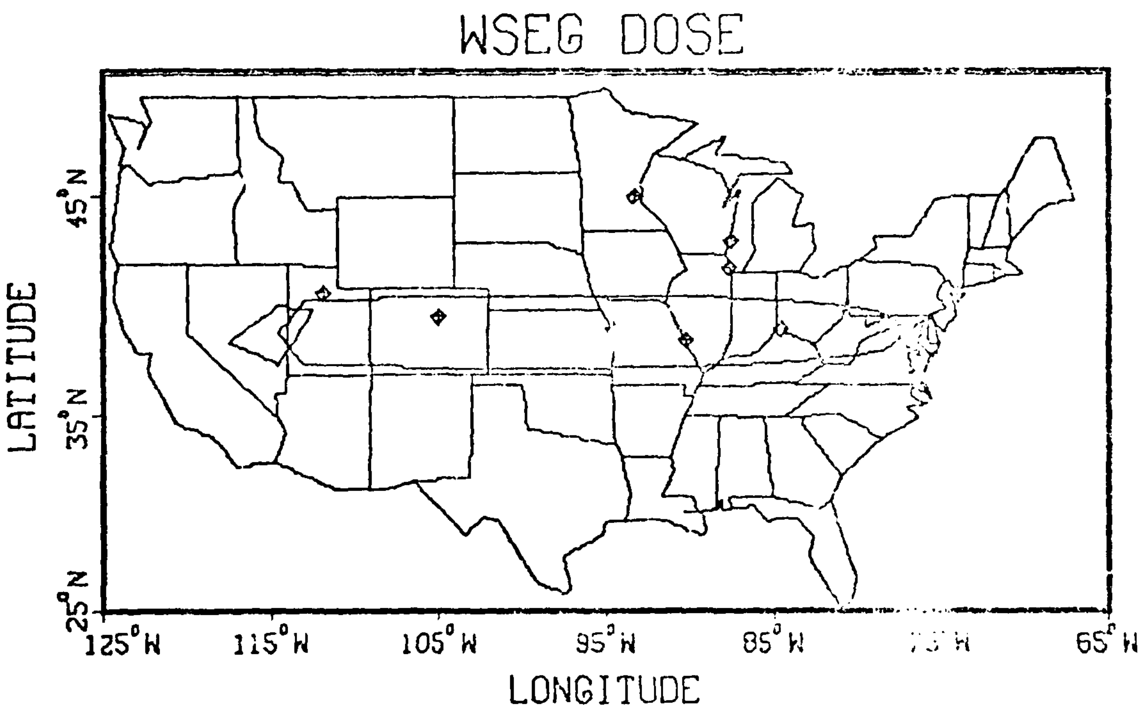




1500 REM CONTOUR. WIND-270/77. '600 1MT BURSTS.

Figure 7c. Average Winter Wind Contours

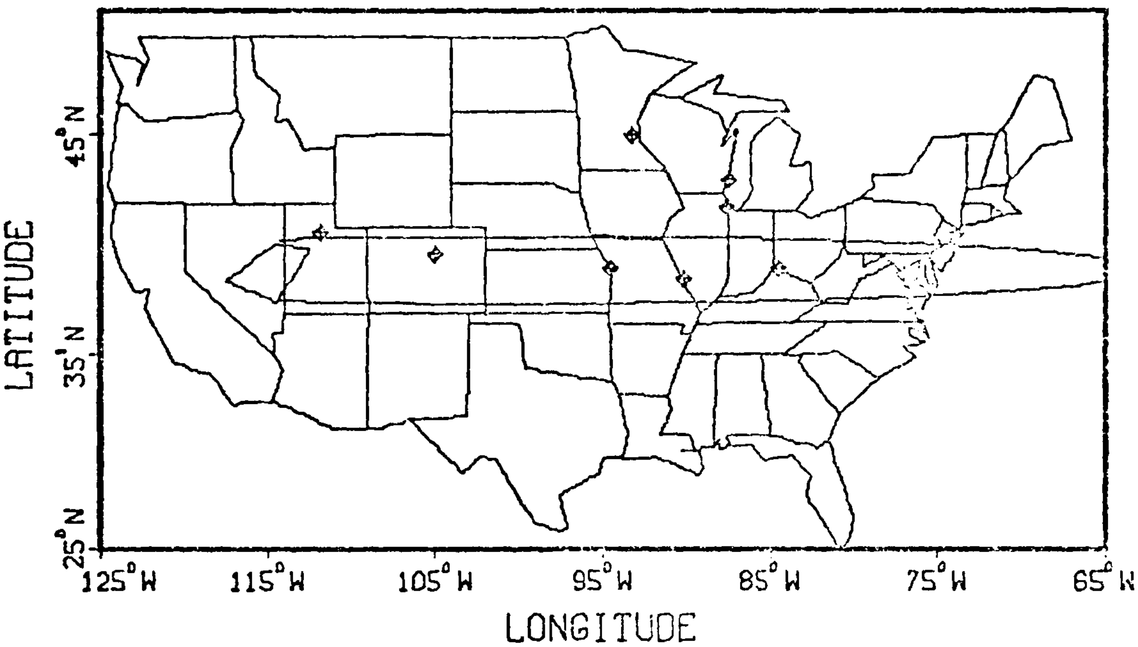




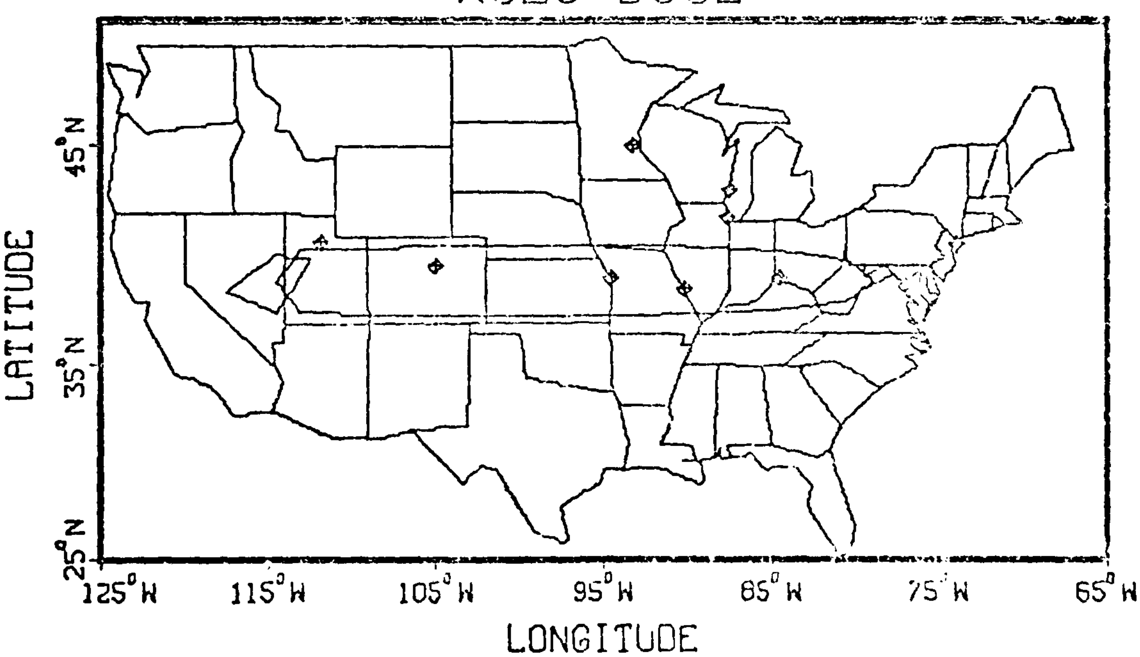
1500 REM CONTOUR. WIND-270/77. 2300 1MT BURSTS.

Figure 7f. Average Winter Wind Contours

AFIT DOSE



WSEG DOSE



1500 REM CONTOUR. WIND-270/77. 4600 .5MT BURSTS.

Figure 7g. Average Winter Wind Contours

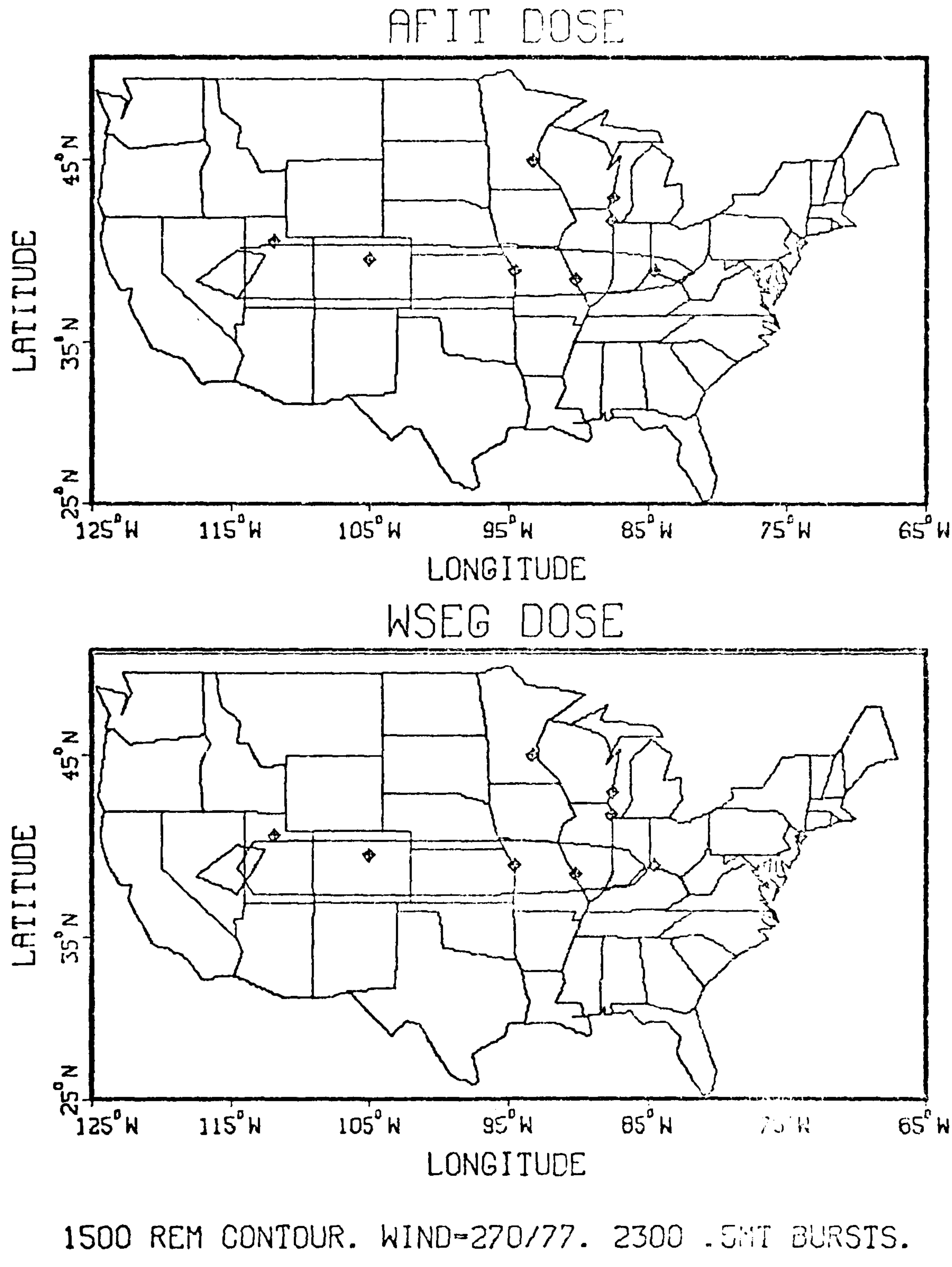
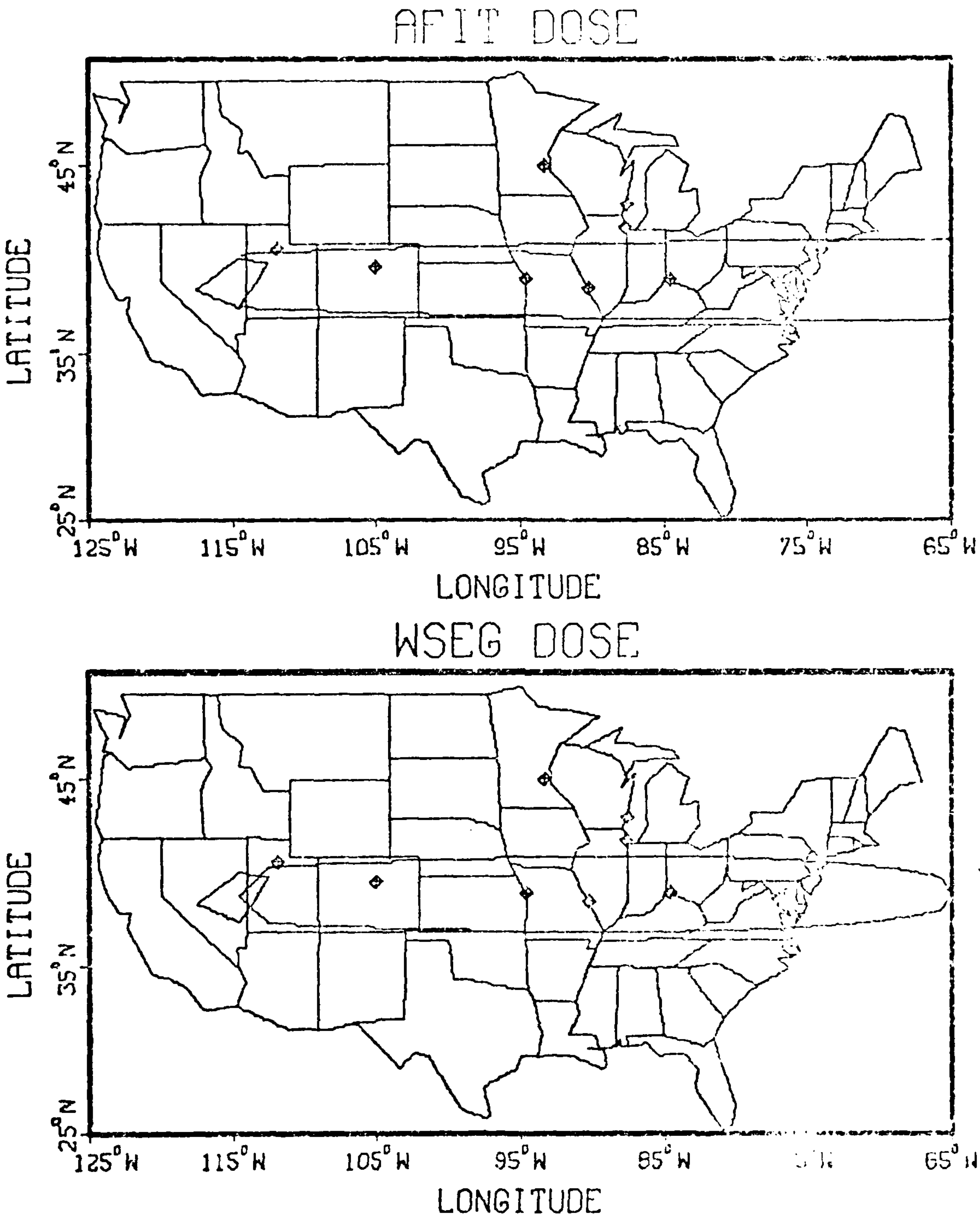
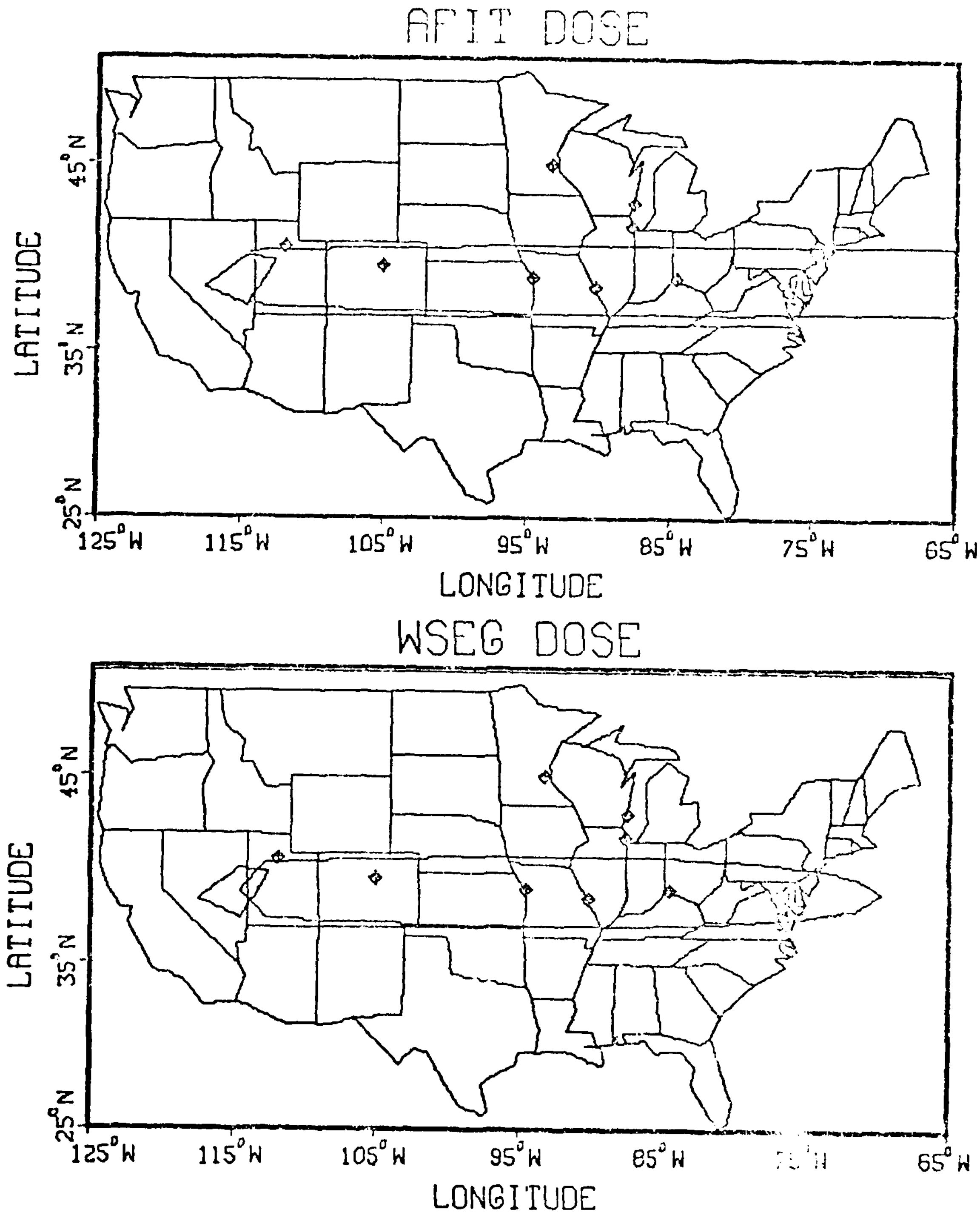


Figure 7h. Average Winter Wind Contours



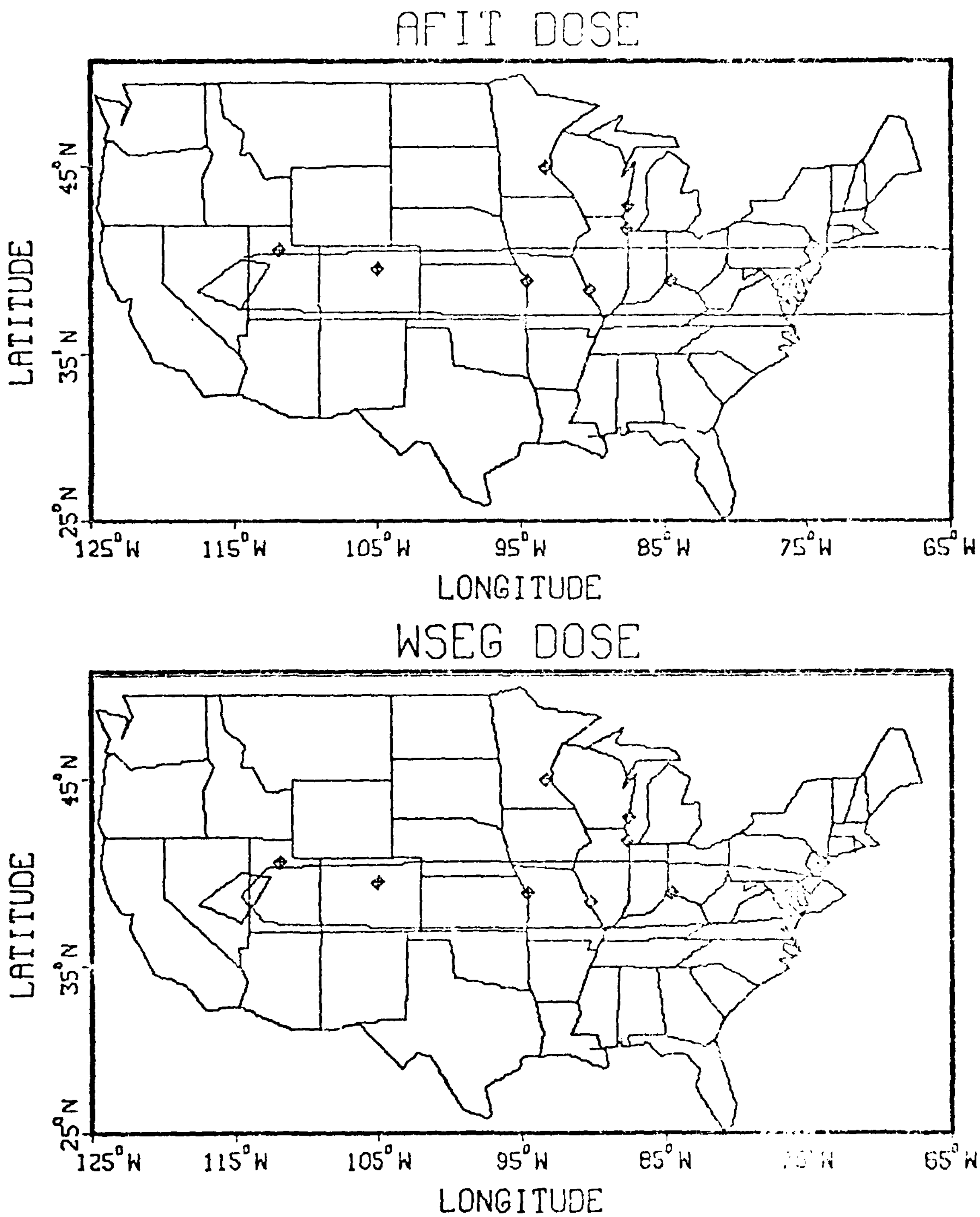
500 REM CONTOUR. WIND-270/70. 4600 1MT BURSTS.

Figure 8a. Strong Summer Wind Contours



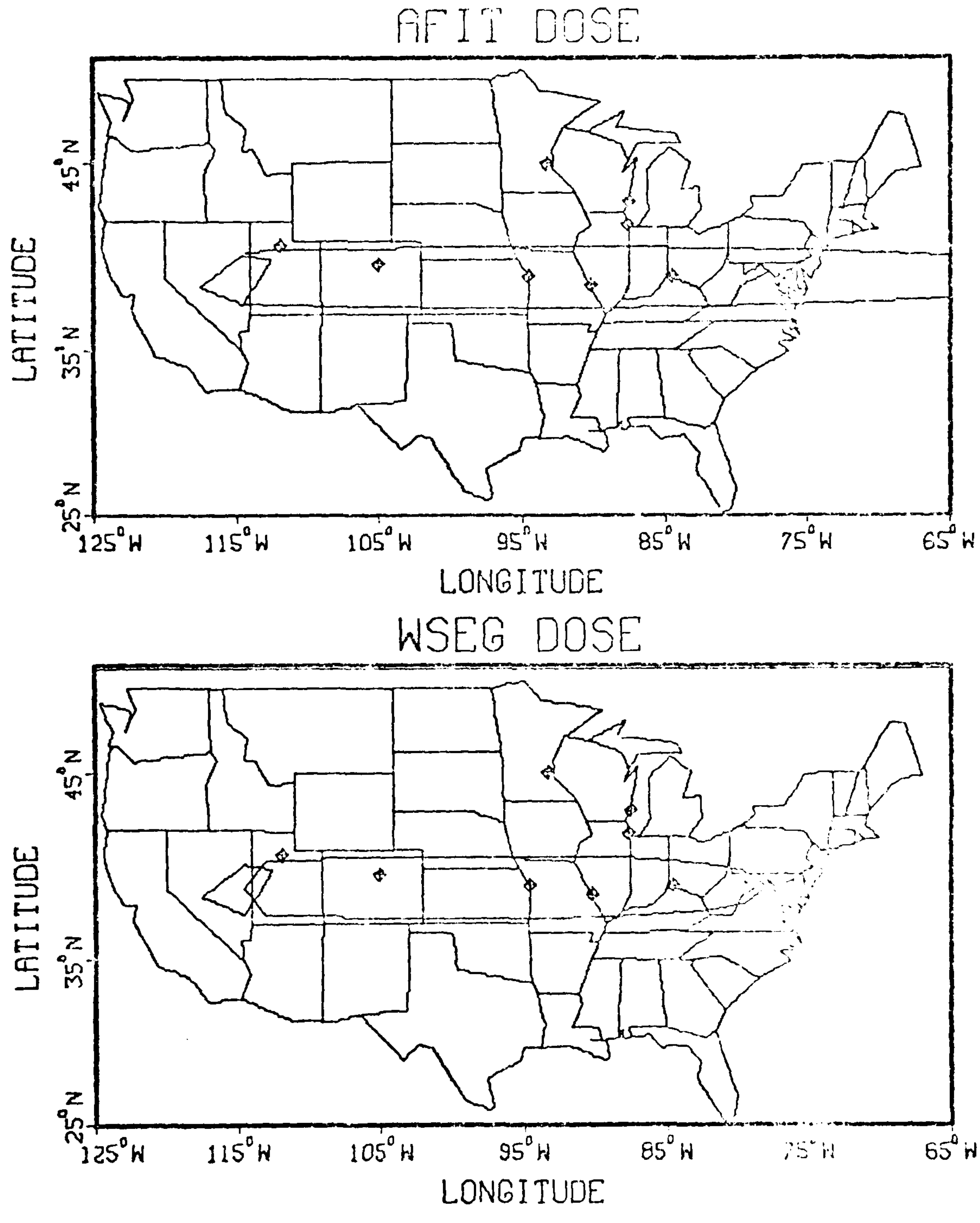
500 REM CONTOUR. WIND-270/70. 2300 1MT BURSTS.

Figure 8b. Strong Summer Wind Contours



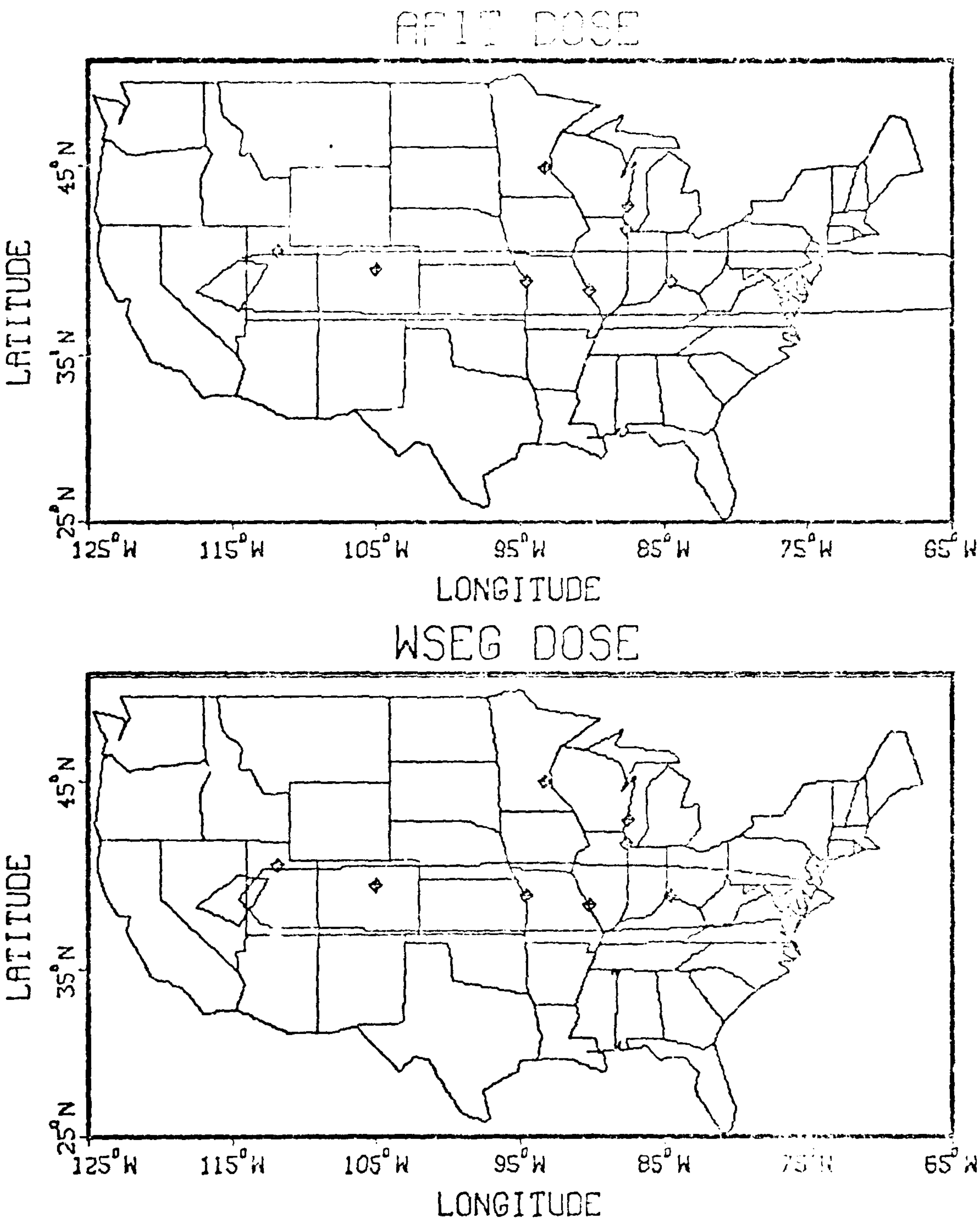
500 REM CONTOUR. WIND-270/70. 4600 .5[illegible]

Figure 8c. Strong Summer Wind Contours



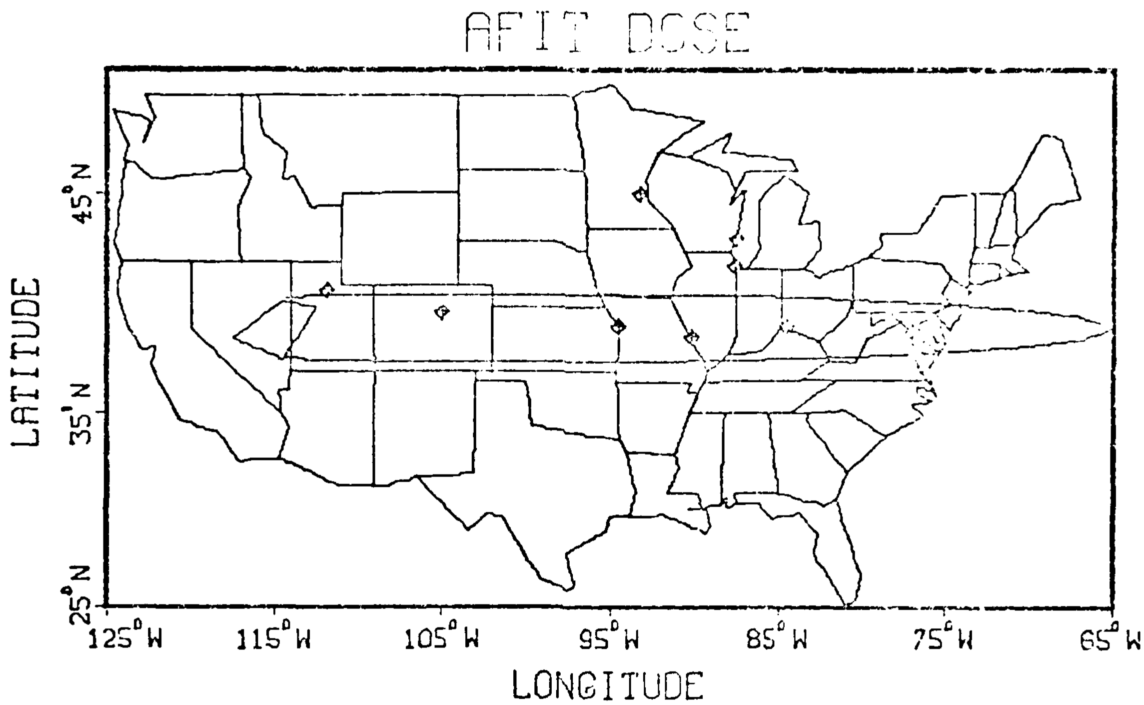
500 REM CONTOUR. WIND-270/70. 2300 .5MT BURSTS.

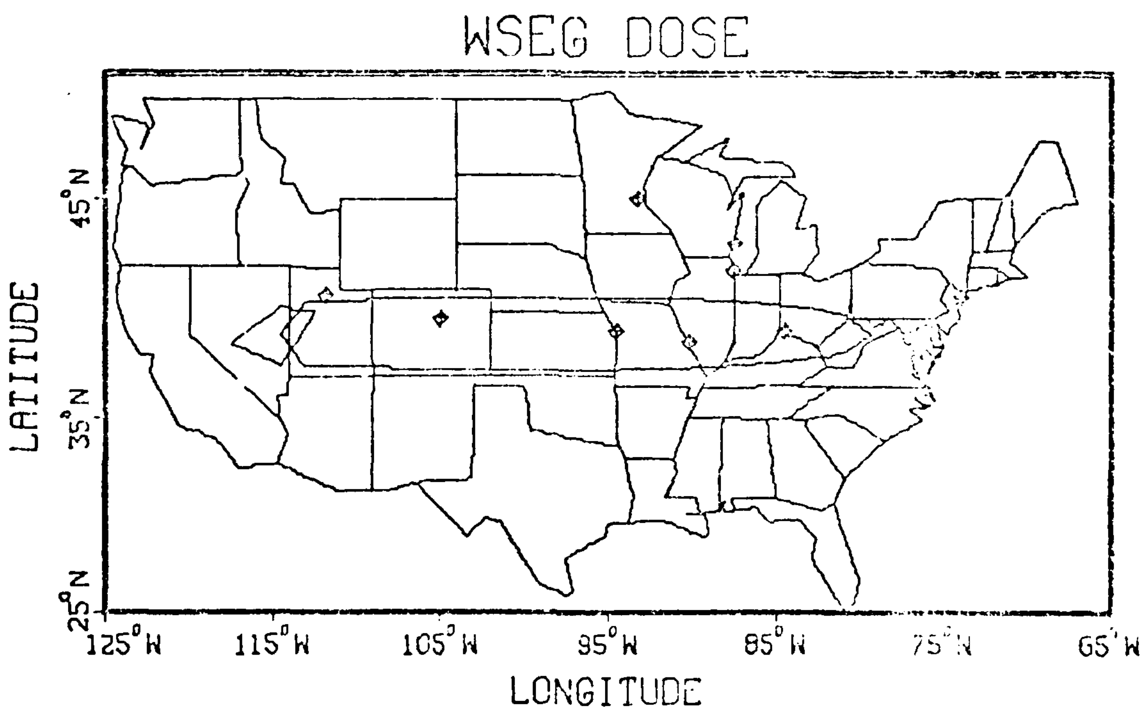
Figure 8d. Strong Summer Wind Contours



1500 REM CONTOUR. WIND-270/70. 4600 1MT BURSTS.

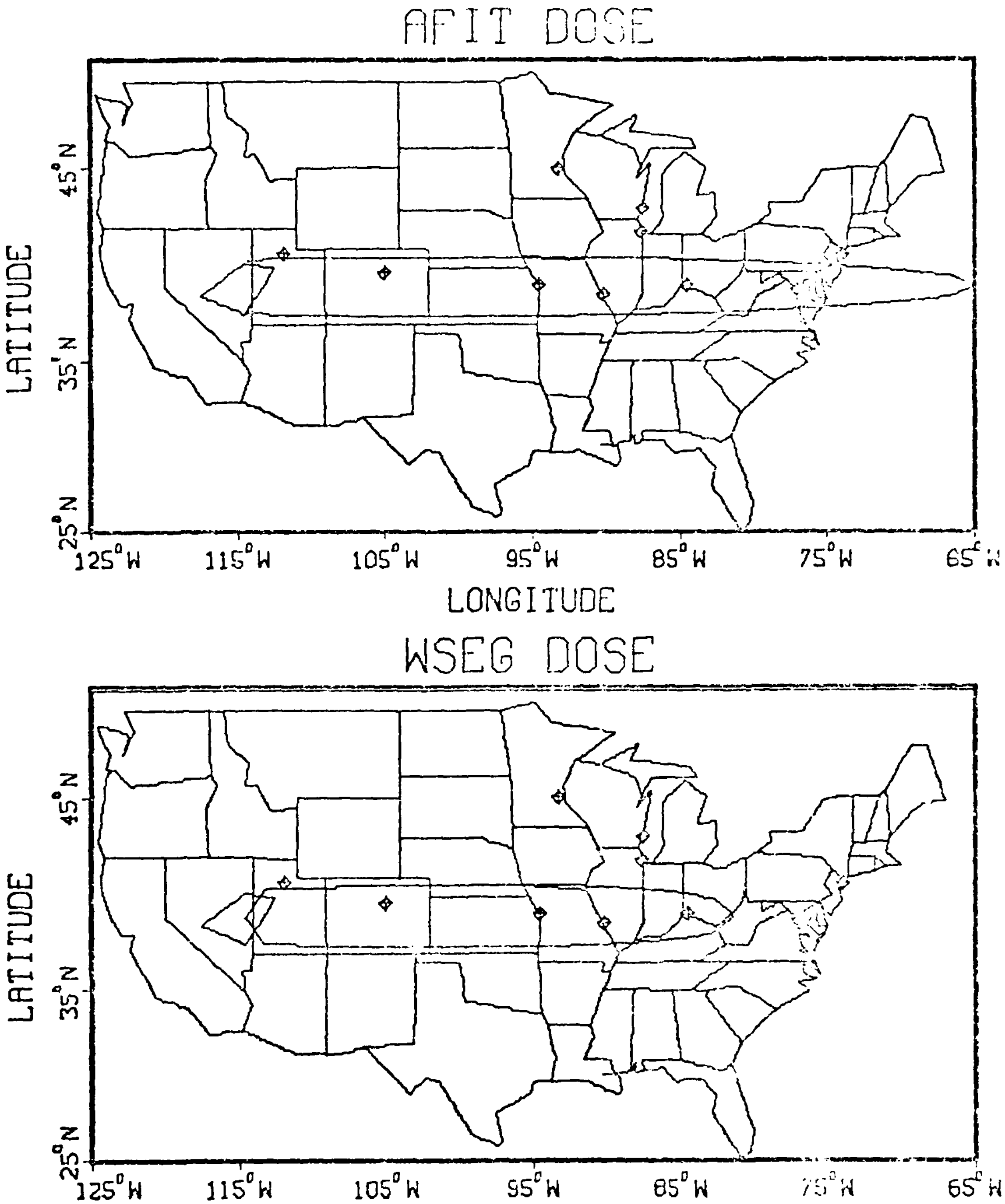
Figure 8c. Strong Wummer Wind Contours





1500 REM CONTOUR. WIND-270/70. 2300 1MT BURSTS.

Figure 8f. Strong Summer Wind Contours



1500 REM CONTOUR. WIND-270/70. 4600 .5MT BURSTS.

Figure 8g. Strong Summer Wind Contours

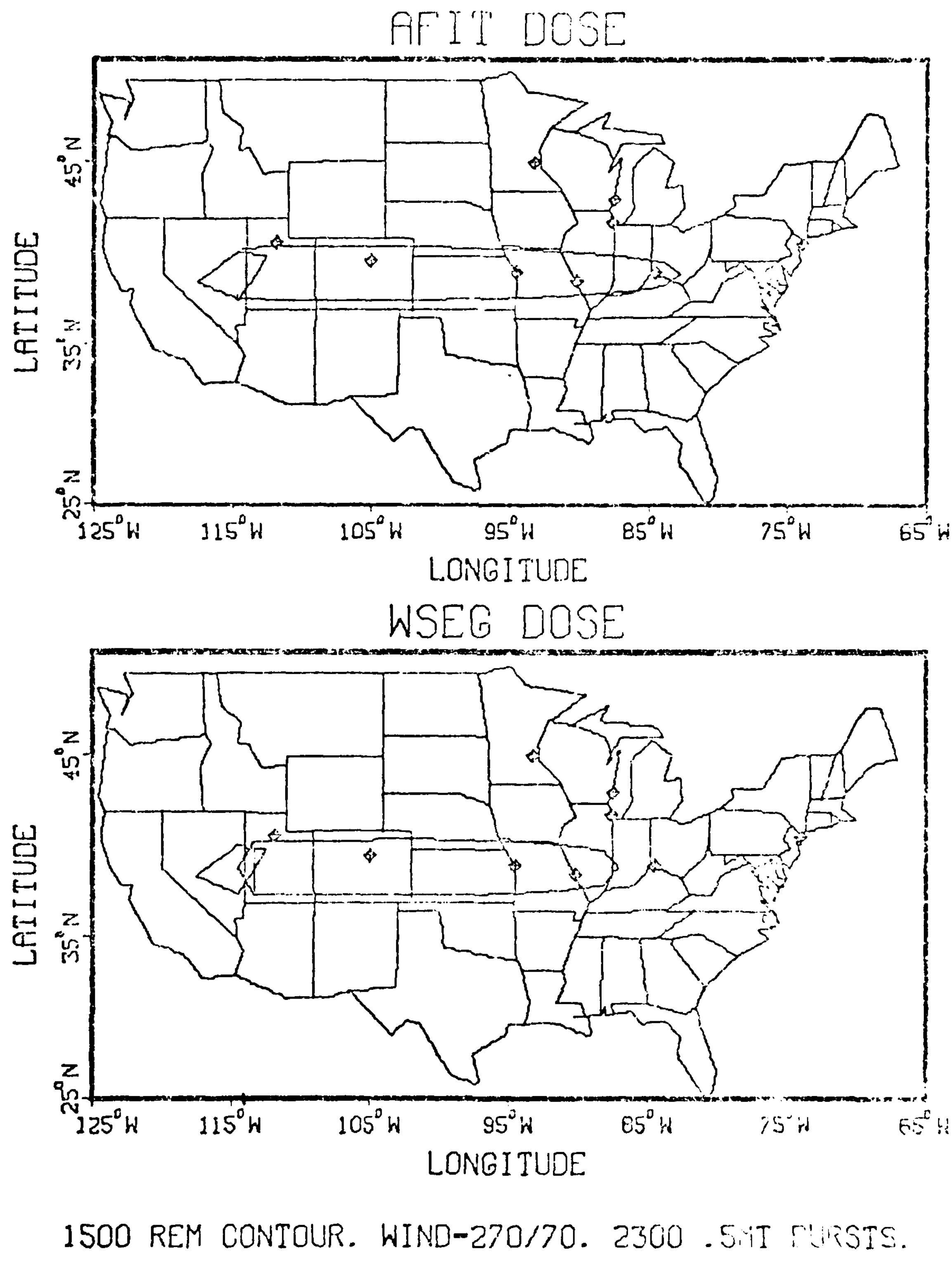
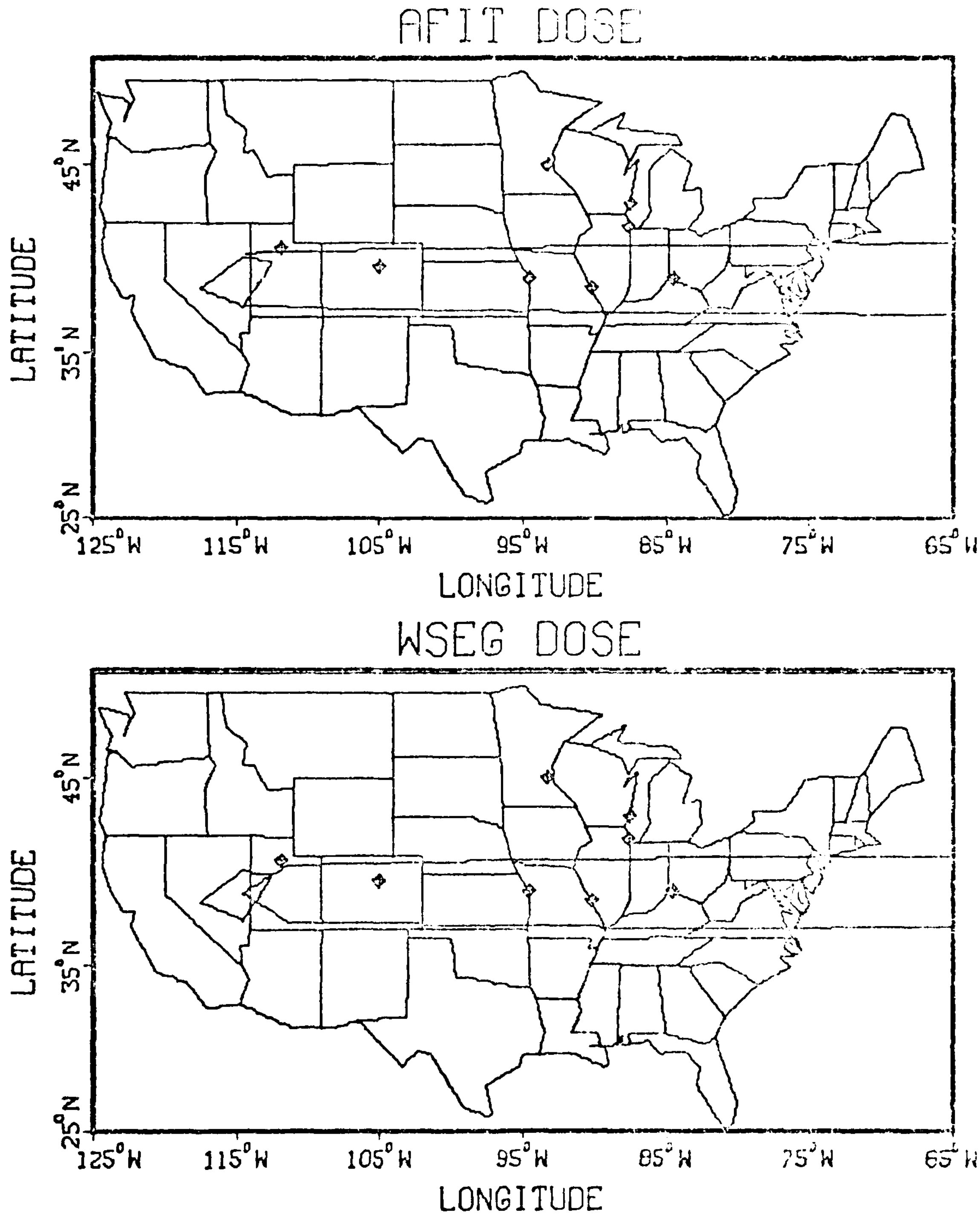


Figure 8h. Strong Summer Wind Contours



500 REM CONTOUR. WIND-270/119. 4600 1MT BURSTS.

Figure 9a. Strong Winter Wind Contours

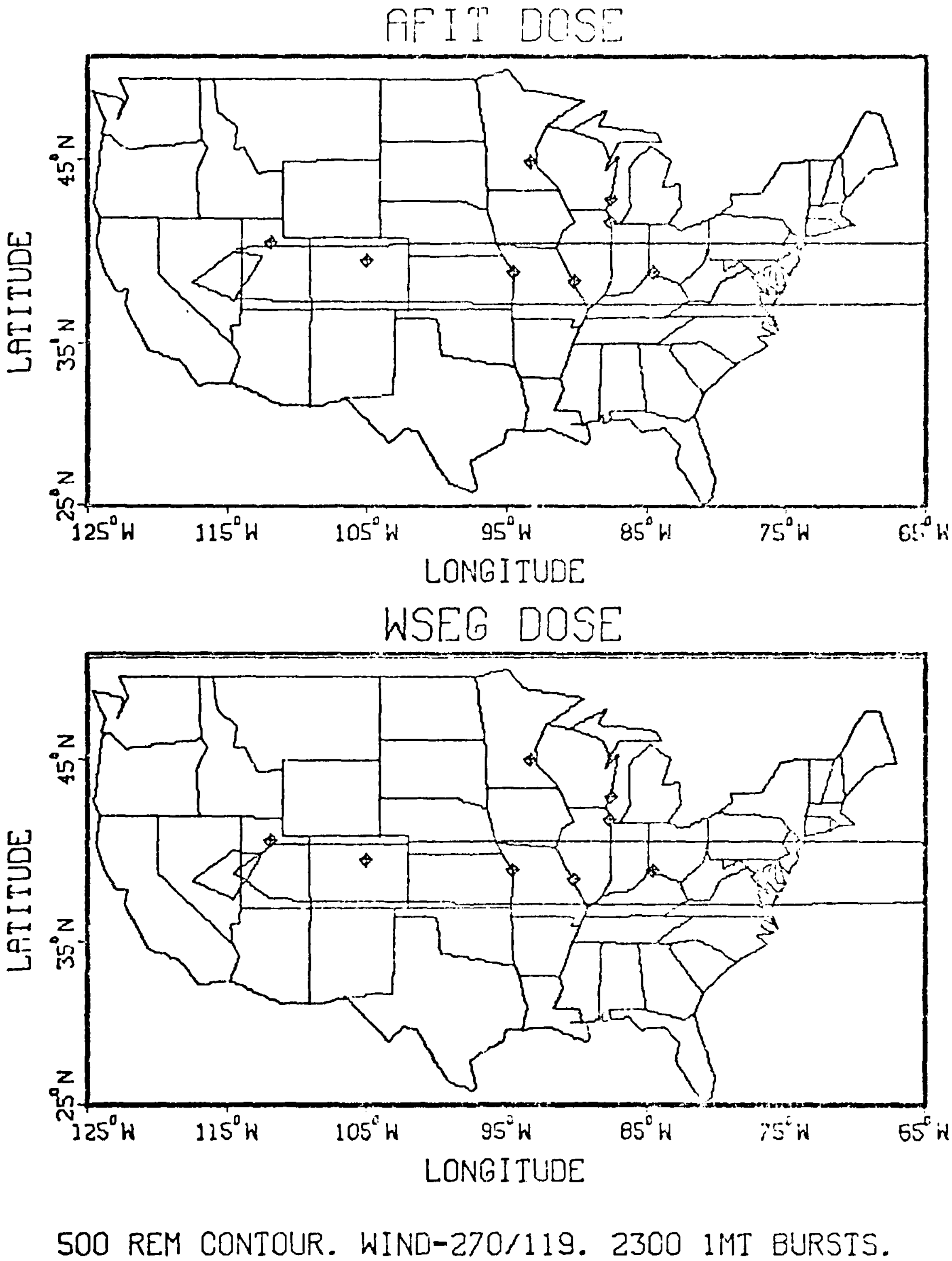
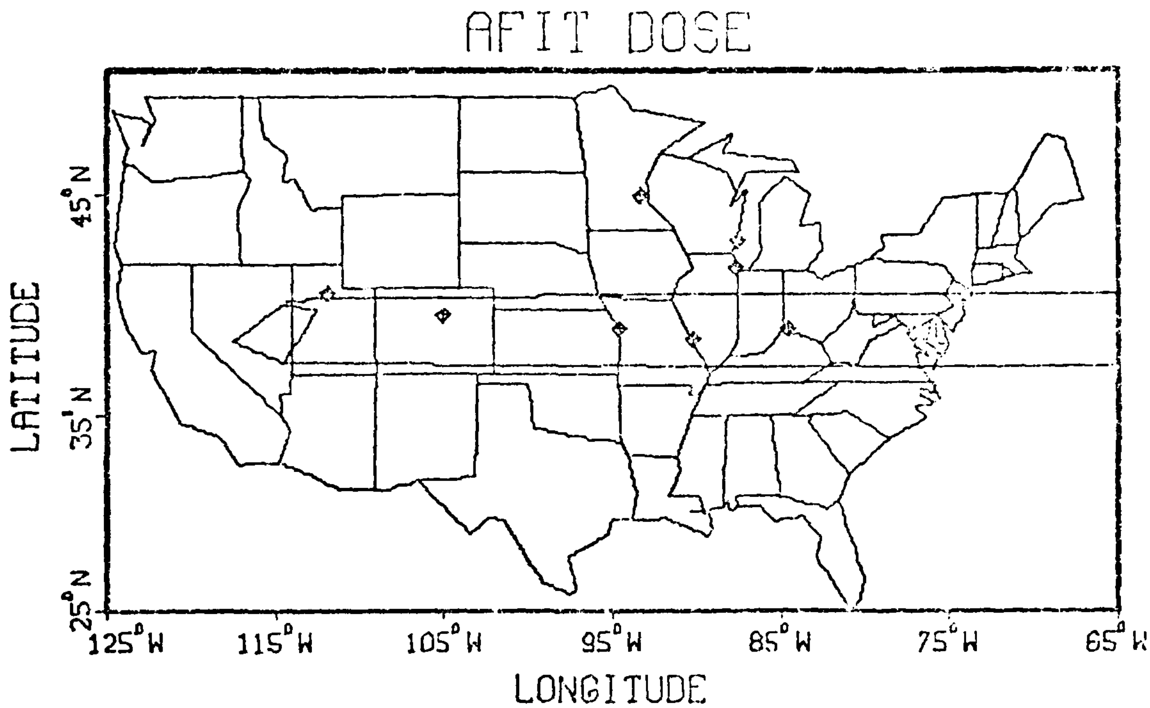
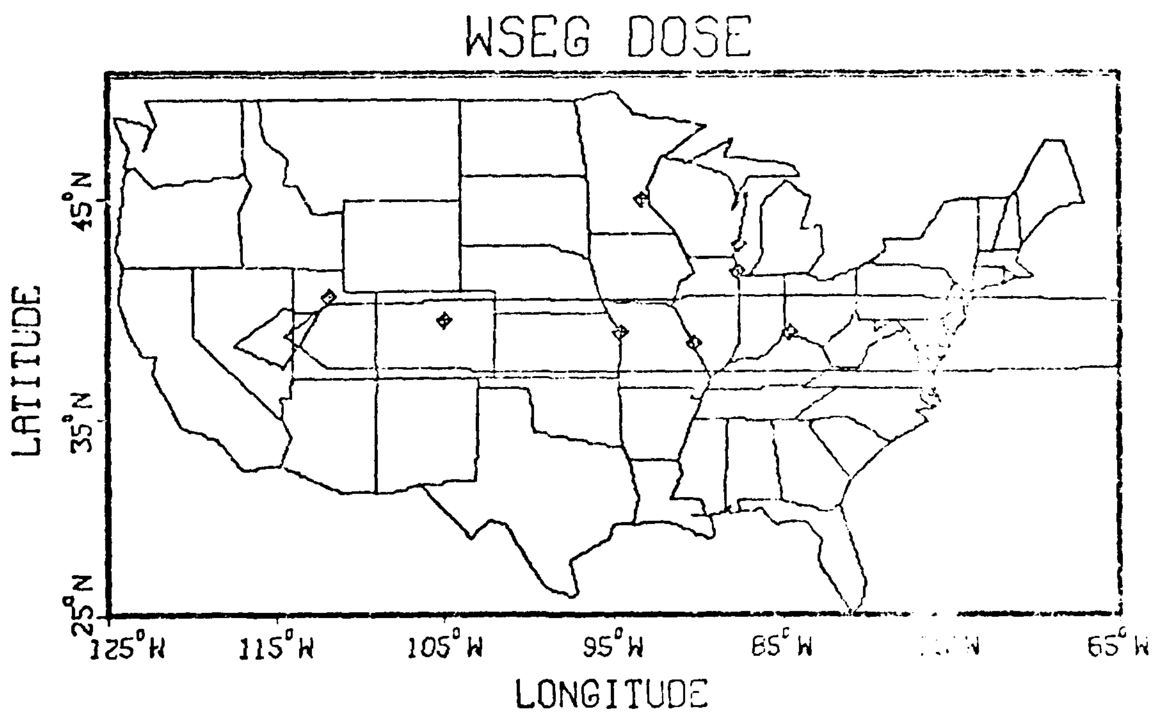


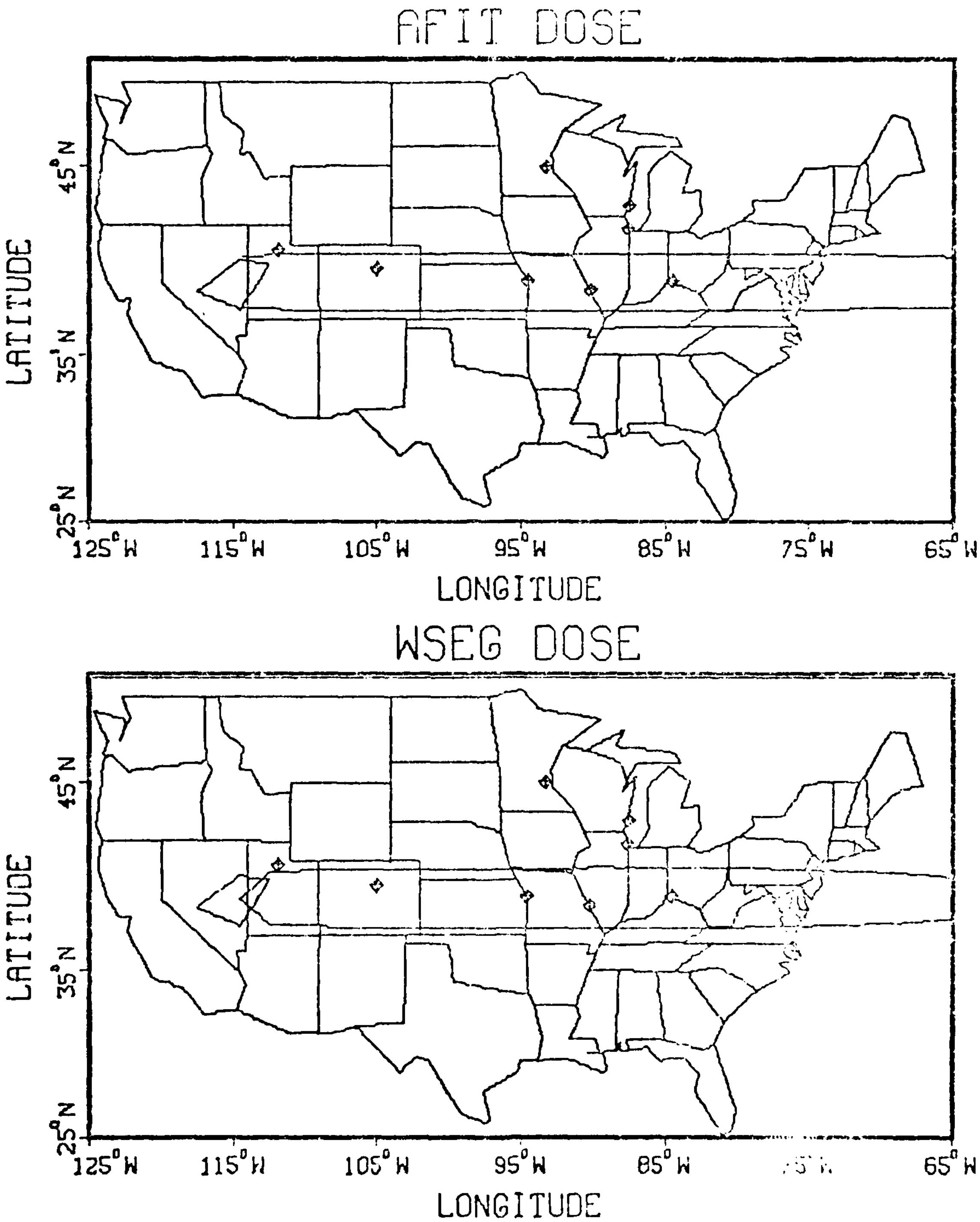
Figure 9b. Strong Winter Wind Contours





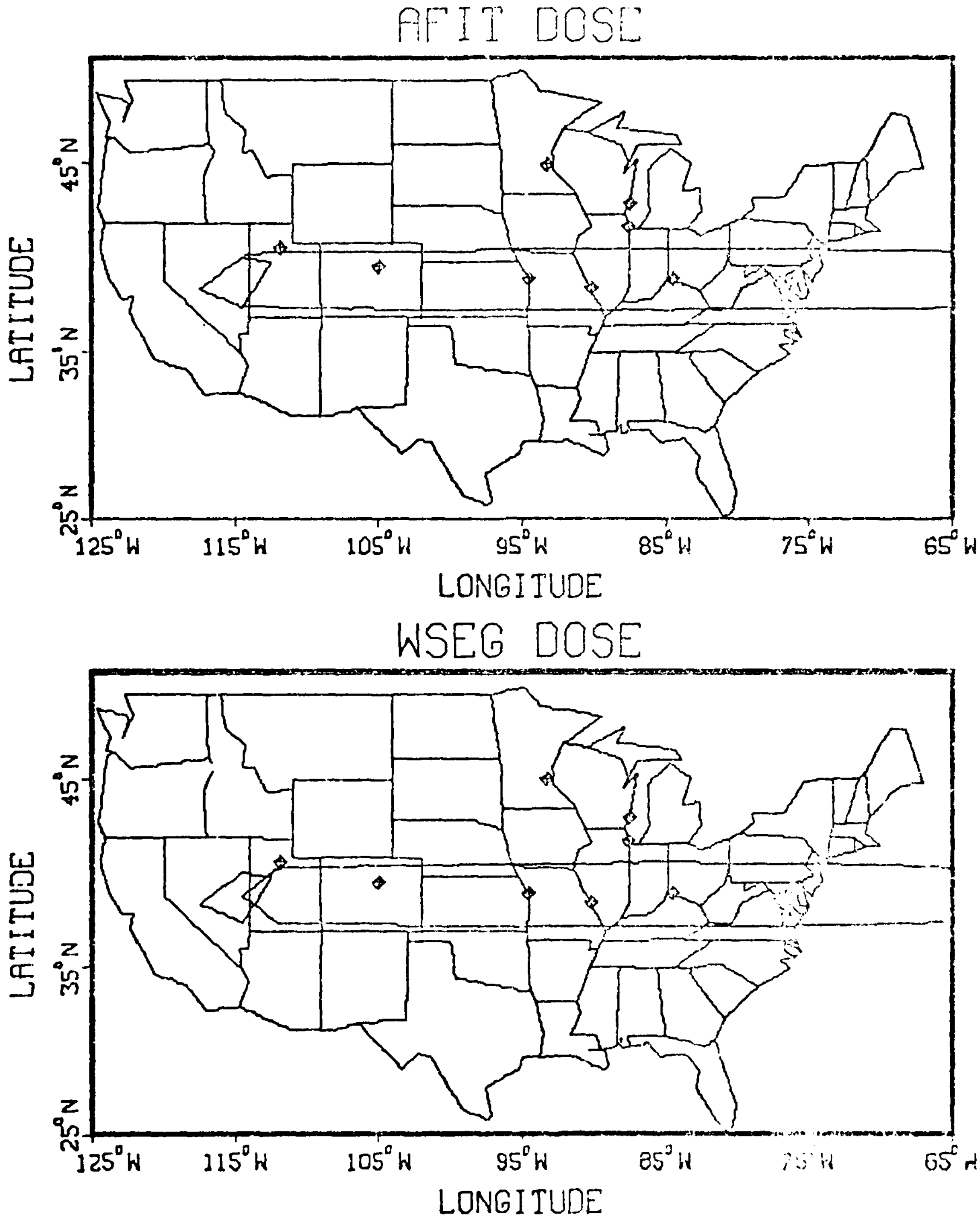
500 REM CONTOUR. WIND-270/119. 4600 .5 [illegible] [illegible]RSTS.

Figure 9c. Strong Winter Wind Contour[illegible]



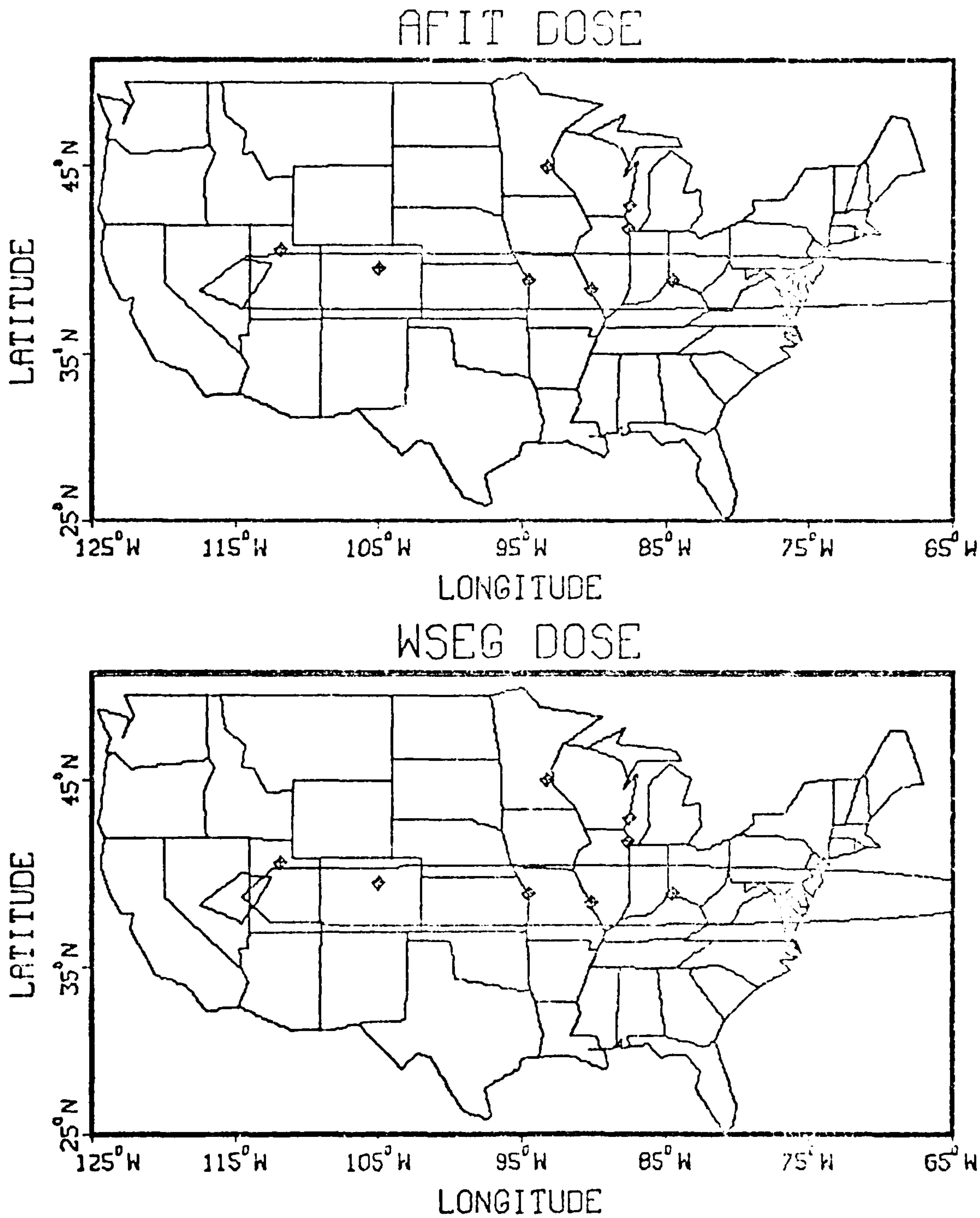
500 REM CONTOUR. WIND-270/119. 2300 .5MT BURSTS.

Figure 9d. Strong Winter Wind Contours



1500 REM CONTOUR. WIND-270/119. 4600 1MT BURSTS.

Figure 9c. Strong Winter Wind Contours



1500 REM CONTOUR. WIND-270/119. 2300 1MT BURSTS.

Figure 9f. Strong Winter Wind Contours

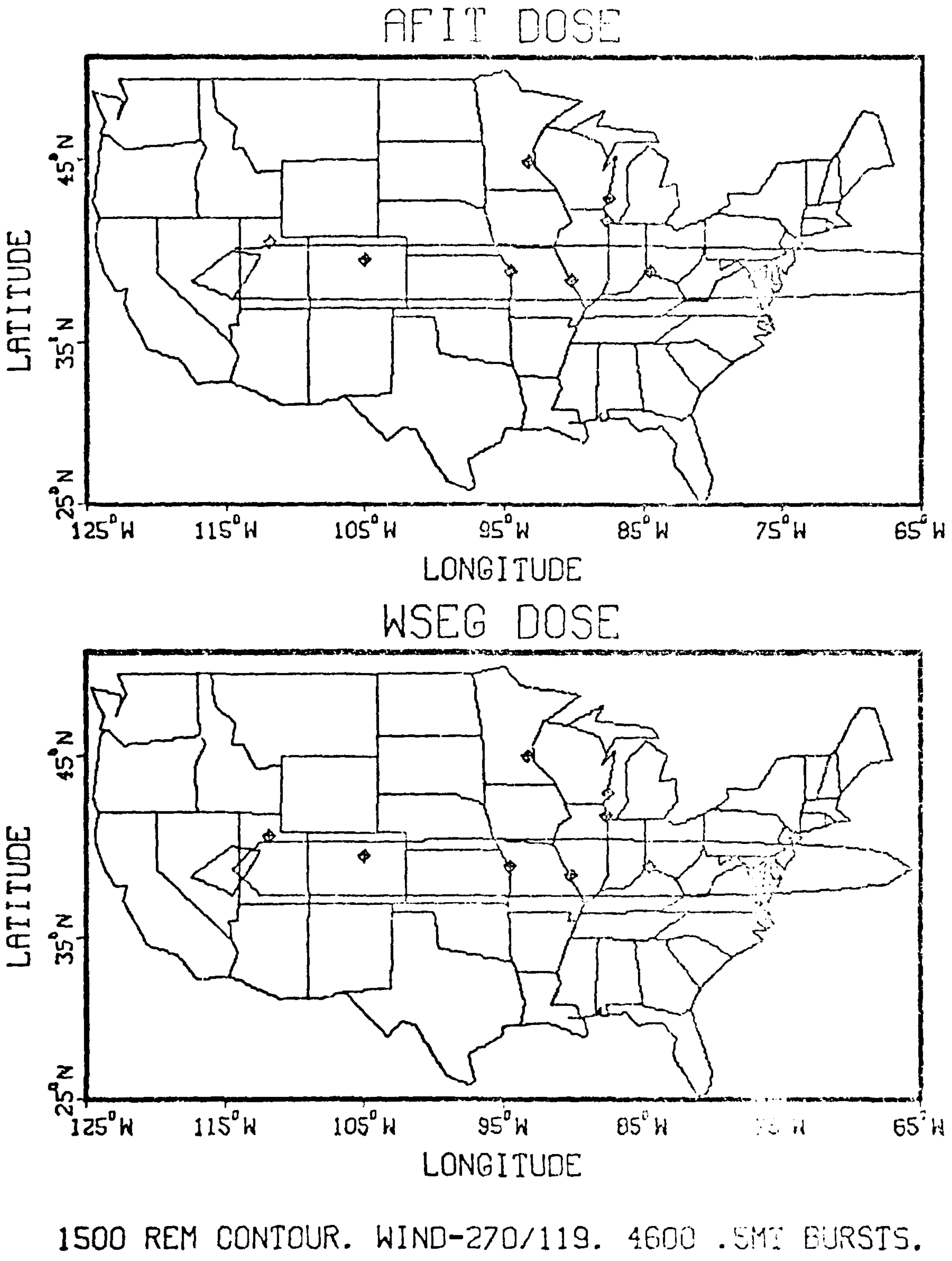


Figure 9g. Strong Winter Wind Contours

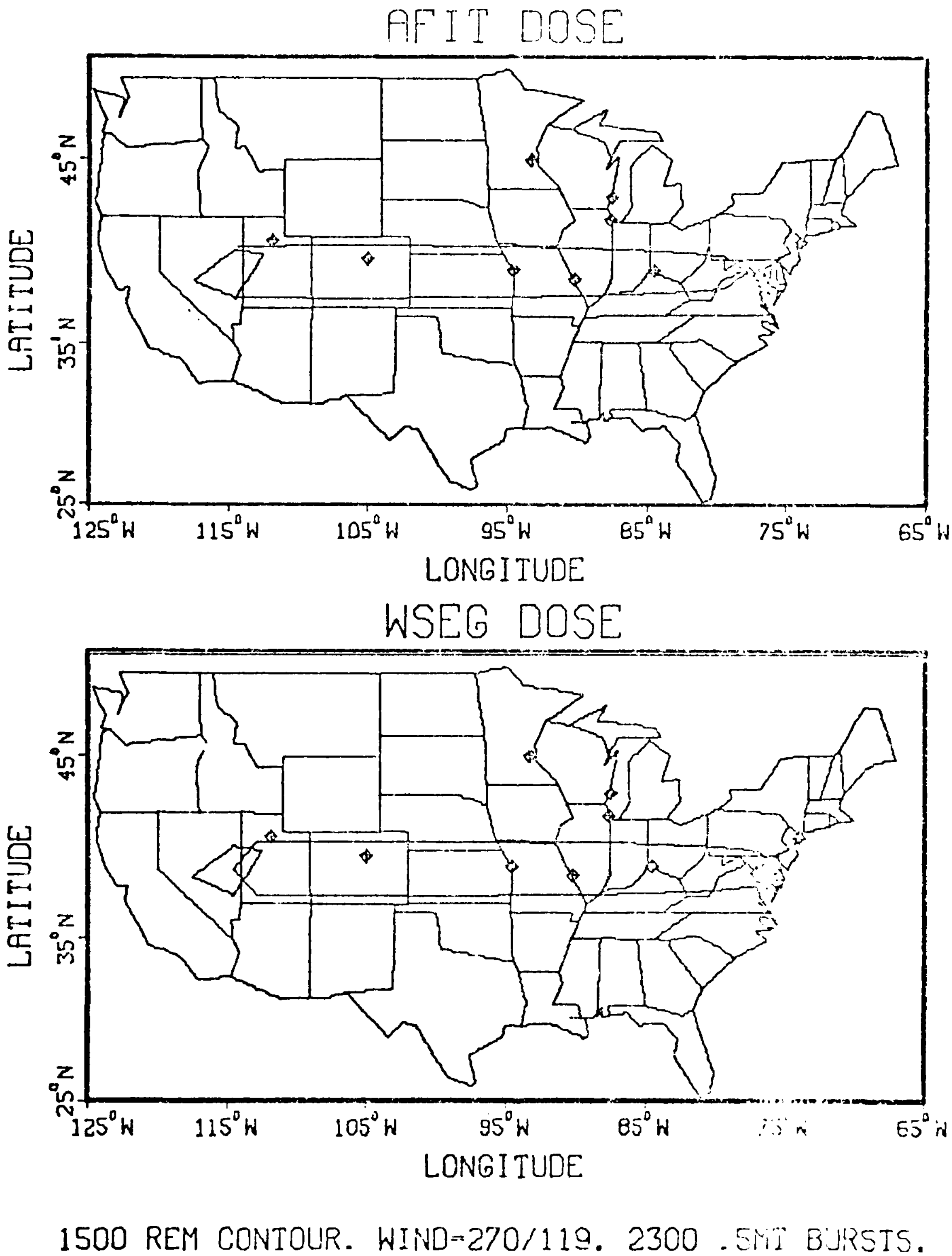


Figure 9h. Strong Winter Wind Contours

V. Conclusions and Recommendations

This paper has presented a method for easily predicting the downwind fallout dosages from a nuclear attack involving many detonations on a target. [illegible] criteria were given which must be met [illegible]; most tactical multi[illegible] cri- teria. Along [illegible] activity distribution [illegible] presented.

This [illegible] operation[illegible] The code [illegible] tions of [illegible] make fairl[illegible] and with [illegible] of time and [illegible] were entered [illegible].

Various in[illegible], and their effect[illegible] desired dose/dose rate [illegible] tion; wind velocity and shear; [illegible] width. The line of bursts is always [illegible] perpendi- cular to the wind. Parameters for the particle [illegible] activity curve must be entered if an AFIT calculation is [illegible]; the WSEG parameters are built into the code.

Recommendations

The presented code will give realistic approximations of the downwind deposition of fallout with great speed and ease. This is exactly what operational planners need to make timely decisions. However, several enhancements could be made to the program to increase its accuracy.

The first enhancement involves wind. The use of a single, constant wind from the surface to 40,000 feet and across the countryside is a notoriously bad approximation. Some way must be devised to incorporate several different winds into the model.

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Appendix A

Fortran Code MULTI

This appendix contains the following items:

- -- a copy of the code MULTI which computes fallout contours, and a glossary of the terms used in MULTI;
- -- A user's guide to running the compiled version of the MULTI program;
- -- a sample of output from MULTI and an explanation of how to interpret the output.

MULTI Code

MULTI is a derivative of SMEAR, a single-burst fallout code written by Dr. Charles J. Bridgman of the Air Force Institute of Technology. Several changes were incorporated into SMEAR to produce MULTI, most notably the multiburst $f(y)$ distribution developed in Chapter II. MULTI was also designed to be run interactively, with inputs coming from both the user and an attached data tape (TAPE4). The user inputs are the parameters of the particular problem to be studied, while the data tape consists of a table of coefficients supplied by Colarco (Ref 3:67-71). The table of coefficients is required in the AFIT calculation of $g(t)$.

The operation of MULTI is straightforward, with all dose/dose rate quantities being calculated as described in

Chapter II. The contour coordinates are given in terms of x (downwind distance from line of bursts) and y (crosswind distance from center of field). These contour coordinates are displayed with the output at the terminal, and are also written on a data tape (TAPE6). This data tape can then be used as the input for contour drawing routines.

The generation of contour coordinates is an iterative procedure. The downwind distance x is increased by a small amount, and the dose (or dose rate) at that x coordinate and the center of the field (or $y = 0$) is then computed and compared to the desired dose. If the computed dose is equal to or less than this desired dose, we are either on or outside of the desired dose contour and the y coordinate is assigned a value of zero. If the computed dose is greater than the desired dose, we are within the desired contour and the y coordinate is increased by a small amount. A new dose is computed for this new (x,y) position. If this computed dose is still greater than the desired dose, the y coordinate is again increased. This procedure continues until the computed dose equals the desired dose; the y coordinate is then the total distance incrementally traveled from the center of the field to this equality point. The downwind distance x is increased again, and a new y coordinate is determined using the same procedure. Twenty-six pairs of (x,y) coordinates are generated to define a desired dose contour.

A glossary of terms used within the code is provided in Table A-1. These terms are presented in order of appearance within the program.

User's Guide to MULTI

Table A-2 shows how the parameters of a problem are entered. The first directive sets up the internal switches for the program:

-- M determines the type of g(t) calculation (0 = WSEG; 1 = AFIT);

-- MD determines the type of output desired (0 = dose rate; 1 = dose);

-- N determines the number of contours to be generated.

The parameters of the scenario are entered next, with the desired contour values entered first. The yield of the attacking weapons (in megatons) and their fission fraction are then requested, as are the average wind velocity (in miles per hour) and crosswind shear. The number of bursts must be entered next, along with the crosswind width of the field (in miles).

If the desired contours are to be computed in terms of dose (that is, MD = 1), the total number of hours over which the dose is to be integrated is entered next. This integration over time is the Way-Wigner approximation (Ref 8:394). If a time of infinity is desired, zero is the required input.

Finally, if all calculations are to be made using the AFIT $g(t)$ (that is, $M = 1$), the parameters of the activity-size distribution curve must be entered. To approximate the DELFIC default, the parameters given in Chapter III should be used.

Interpretation of Output from MULTI

Table A-3 is the output of the scenario entered in Table A-2. A short summary of some of the input data is first given. "AFIT CALCULATION" means the program will utilize the AFIT $g(t)$ in its computations. The yield, fission fraction, wind and wind shear are printed out, as is the desired dose contour. The 26 pairs of coordinates for the contour are then listed. Note that this listing is just "half" a contour; due to the symmetry of the cloud, the other "half" of the contour has the same x coordinates but the negative of the y coordinates.

```
      PROGRAM   MULTI(INPUT,OUTPUT,TAPE5,TAPE6)
C   TAPE5 IS A DATA [illegible] USED FOR WSEG CALCULATIONS.
C   TAPE6 IS AN OUTPUT TAPE FOR COMPUTED VALUES.
C
      DIMENSION X(25),Y(25)
      COMMON D([illegible]),DM([illegible]),D([illegible]),AL,BT
      COMMON TC,SIGO,SIGH,SHR,SC,VX,TP,TM,TF,K,M,MD
      COMMON NN,W,TD
C
C   INTERNAL SWITCHES =
C      M=0 FOR WSEG, M=1 FOR AFIT
C      MD=0 FOR DOSE RATE(R/HR), MD=1 FOR DOSE(R)
C   N IS THE NUMBER OF CONTOURS TO BE COMPUTED
C
      PRINT*,"ENTER M(0 OR 1),MD(0 OR 1),AND N(# CONTOURS)= "
      READ *,M,MD,N
C   READ N VALUES OF CONTOURS REQUESTED IN R/HR OR R
      PRINT*,"ENTER CONTOUR VALUES= "
      READ*,(D(I),I=1,N)
C   READ YIELD (IN MT),FRACTION OF YIELD AS FISSION,
C    WIND (IN MI/HR), AND WIND SHEAR (IN HR-1)
      PRINT*,"ENTER YIELD,FRACTION,WIND LEVEL, AND WIND SHR= "
      READ *, YM,FF,VX,SHR
      PRINT*,"ENTER # OF BURSTS= "
      READ*,NN
      PRINT*,"ENTER N-S WIDTH OF FIELD= "
      READ*,W
      W=W/2.
      IF(MD.EQ.1.)PRINT*,"ENTER TIME OF DURATION= "
      IF(MD.EQ.1.)READ*,TD
C   SC (SOURCE NORMALIZATION CONSTANT) YIELDS R OR R/HR
      IF(M.EQ.[illegible].)SC=2.E+[illegible]*FF*YM
      IF(M.EQ.1.)SC=2.35[illegible]E+[illegible]*FF*YM
C
C   YIELD DEPENDENT CONSTANTS ARE NOW COMPUTED
C    HC IS IN KILOFEET
C    SIGH AND SIGO ARE IN STATUTE MILES
C    TC IS IN HOURS
      HC= [illegible]*ALOG(YM)-.[illegible]*(ALOG(YM)+2.[illegible])*ABS(ALOG(YM)
     &     +2.[illegible])
      SIGH = .1[illegible]*HC/[illegible]
      SIGO = EXP(.7[illegible]+ALOG(YM)/[illegible]. - [illegible]/([illegible]+(ALOG(YM)+[illegible])[illegible]))
C    TC = 1.[illegible]*(12.[illegible]HC/[illegible]HC/[illegible])*(1.-.[illegible]
     &      -HC*HC/52[illegible].))

C   SET ALPHA AND BETA FOR WSEG CALCULATIONS
      AL = 44.
      BT = .69
C   IF THIS IS A WSEG CALCULATION,SKIP TO 6[illegible]
      IF (M.EQ.0) GOTO 6
            PRINT*,"ENTER ALPHA AND BETA = "
            READ *, AL,BT
```

```
C         CONVERT KILOFEET TO KILOMETERS
              ZK=4D*.3.1.
C         DERIVE CONSTANTS FOR G(T)
              DO 25 J=2,5
              C(J-1)=COEFF(ZK,J)
 25           CONTINUE
              DO 26 J=7,9
              C(J-2)=COEFF(ZK,J)
 26           CONTINUE
              PRINT 55
 55           FORMAT (* AFIT CALCULATION *)
C     IF THIS IS A WSEG CALCULATION, PRINT THAT
 60     IF (M.EQ.2) PRINT 65
 65     FORMAT(* WESG CALCULATION *)
      PRINT OUT THE INPUT PARAMETERS
        PRINT 70,YM,FF
 70     FORMAT(* YIELD = *,F8.2,* MT. FISSION FRACTION = *,F5.2)
        PRINT 75, VX,SHF
 75     FORMAT(* WIND = *,F8.1,* MPH. WIND SHEAR = *,F5.3,* HR-1*)
        PRINT 80
 80     FORMAT (* ACTIVITY-SIZE DISTRIBUTION IS LOGNORMAL *)
        PER = 1 0.
        PRINT 82,PER, AL,BT
 82     FORMAT(1X,F5.2,* % HAS AN ALPHA = *,F6.1,* AND A BETA =*,
     &    F5.3)
C
C     FIND THE TIME OF MAXIMUM G(T) AND CALL IT "TM"
 86     CALL GMAX
C
             DO 120 K=1,N
C         FIND UPSLOPE INTERSECTION BY CALLING "UPHILL"
             CALL UPHILL
C         RETURN WITH VALUE FOR TB
             IF (TB.EQ.-(3.) GOTO 12.
C         FIND DOWNSLOPE INTERSECTION BY VALLING "DWHILL"
             CALL DWHILL
C         RETURN WITH VALUE FOR TF
C         DIVIDE HOT LINE INTO 25 INTERVALS
             DT =(TF-TB)*.04
C
C         PRINT TABLE TITLE FOR APPROPRIATE CALCULATION
             IF (MD.EQ.1) PRINT 90, D(K)
 90          FORMAT(* COORDINATES FOR *,F7.1,* R/HR ISORATE LINE*)
             IF (MD.NE.1) PRINT 95, D(K)
 95          FORMAT(* COORDINATES FOR *,F7.1,* R ISODOSE LINE*)
C         COMPUTE AND PRINT X,Y VALUES FOR THIS CONTOUR
C          X IS DOWNWIND DISTANCE FROM BURSTS
C          Y IS CROSSWIND DISTANCE FROM HOTLINE
                 DO 111 I = 1,25
                 T = FLOAT(I-1)*DT    + TB
                 X(I) = VX*T
C         FIND DOSE ON THE HOT LINE FOR EACH STEP X(I)
                 Y(I)=
                 Z=ABS((Y(I)-W)/SIGY(X(I)))
```

```
C         CUM. NORMAL FUNCTION AS GIVEN BY
C          ABRAMOWITZ AND STEGUN, P.932
                 F=1./(2.*(1.+.196854*Z+.115194*Z*Z
     *          +.000344*Z**3+.019527*Z**4)**4)
                 FA=1.-F
                 FB=FA-F
                 FY=NN/(2*W)*FB
                 D=SC*G(T)/VX*FY
                 IF(MD.NE.0) D = D+BI(T)
C         IF DOSE ON THE HOT LINE IS GREATER THAN THE DESIRED DOSE
C          GO CROSSWIND UNTIL DESIRED DOSE IS INTERSECTED.
                 IF (D.GT.D(K)) GOTO 10.
                 Y(I) = 0.
                 GOTO 105
C
C         DETERMINATION OF CROSSWIND DISTANCE NEEDED
C          TO INTERSECT DESIRED DOSE
 10?             A=0
                 MAXW=(W+3*SIGY(X(I)))*10.
                 DO 106 J=1,MAXW
                 A=A+.1
                 Z=ABS((A-W)/SIGY(X(I)))
                 F=1./(2.*(1.+.196854*Z+.115194*Z*Z
     *          +.000344*Z**3+.019527*Z**4)**4)
                 IF(A.LT.W)F=1.-F
                 FY=NN/(2*W)*F
                 D=SC*G(T)/VX*FY
                 IF(MD.NE.0.)D=D+BI(T)
                 IF(D.GT.D(K))GO TO 106
                 Y(I)=A
                 GO TO 105
 106             CONTINUE
 105             PRINT 110,I,X(I),Y(I)
                 WRITE(6,112),X(I),Y(I)
 110             FORMAT (I5,2F8.1)
 112             FORMAT(10X,2F10.2)
 111             CONTINUE
C
C         PRINT THE FINAL POINT
             X(26) = VX*TF
             Y(26) = 0.
             PRINT 110,26,Y(26),Y(26)
             WRITE(6,112),X(26),Y(26)
 120         CONTINUE
          STOP
          END
```

```
C*****************************************************************
      SUBROUTINE GMAX
      COMMON D(4),DM(  0),G(7),AL,BT
      COMMON TO,SIGO,SIGH,SHR ,SC,VX,TB,TM,TF,K,M,MD
      COMMON NN,W,TD
C   MAXIMUM G(T) IS FOUND BY TRACING G(T)
C    TO ITS PEAK IN .1 HOUR INCREMENTS
             DO 4 J=1,1 0
             T=FLOAT(J-1)*.1
             DM(J)=G(T)
             IF (J.EQ.1) GOTO  4
             IF (DM(J).LT.DM(J-1)) GOTO  5
  4          CONTINUE
  5   TM=T-.1
      RETURN
      END
C*****************************************************************
      SUBROUTINE UPHILL
      COMMON D(4),DM(  0),G(7),AL,BT
      COMMON TO,SIGO,SIGH,SHR ,SC,VX,TB,TM,TF,K,M,MD
      COMMON NN,W,TD
C   THIS SUBROUTINE FINDS THE POINT ON THE HOTLINE
C    CLOSEST TO THE BURSTS WHERE THE DESIRED CONTOUR
C    DOSE INTERSECTS.
C
C   TB= -99. IS A FLAG TO INDICATE THAT J=1  IS LESS THAN TM
      TB = -99.
C   TO=INITIAL TIME
      TO = -(3.*SIGO)/VX
      IF (M.NE.0) TO = 0.
      T=TO
C   SET DT FOR WSEG (FOR T < 3*SIGMA)
      DT = .1*ABS(TO)
      DM(1) = 0.
           DO 2 J=2,1
C          SET DT FOR AFIT OR RESET IT FOR WSEG
           IF(T.GE.ABS(TO)) DT=. 1
           T = T + DT
           X = T*VX
           Z=W/SIGY(X)
           F=1./(2.*(1.+.196  *Z+.115194*Z*Z
     *     +.000344*Z**3+.019527*Z**4)**4)
           FA=1.-F
           FB=FA-F
           FY=NN/(2.*W)*FB
           DM(J)=SC*G(T)/VX*FY
           IF(MD.NE.0) DM(J) = BI(T)*DM(J)
           IF (DM(J).GE.D(K)) GOTO 3
           IF(T.GT.TM) RETURN
  2        CONTINUE
      RETURN
C   INTERPOLATE
  3   DLT = DT*(DM(J)-D(K))/(DM(J)-DM(J-1))
      TB=T-DLT
      RETURN
      END
```

```
C*************************************************************
      SUBROUTINE DWHILL
      COMMON D(4),DM(500),C(7),AL,BT
      COMMON TO,SIGO,SIGH,SHR,SC,VX,TB,TM,TF,K,M,MD
      COMMON NN,W,TD
C   THIS SUBROUTINE FINDS THE POINT ON THE HOTLINE
C    FARTHEST FROM THE BURSTS WHERE THE DESIRED DOSE INTERSECTS.
C
      JL = TM/.5 + 2.
            DO 4 J = JL,500
            T = FLOAT(J-1)*.5
            X = T*VX
            Z=W/SIGY(X)
            F=1./(2.*(1.+.196854*Z+.115194*Z*Z
     *      +.000344*Z**3+.019527*Z**4)**4)
            FA=1.-F
            FB=FA-F
            FY=NN/(2.*W)*FB
            DM(J)=SC*G(T)/VX*FY
            IF(MD.NE.0) DM(J)=RI(T)*DM(J)
            IF(D(K).GT.DM(J)) GOTO 5
  4         CONTINUE
C   INTERPOLATE
  5   DLT = .5*(D(K)-DM(J))/(DM(J-1)-DM(J))
      TF =  T -DLT
      RETURN
      END
C*************************************************************
      FUNCTION G(S)
      COMMON D(4),DM(500),C(7),AL,BT
      COMMON TO,SIGO,SIGH,SHR,SC,VX,TB,TM,TF,K,M,MD
      COMMON NN,W,TD
C   THIS SUBROUTINE COMPUTES G(T) FOR AFIT OR WSEG.
C
      IF (M.EQ.2) GOTO 4
      IF (S.LT..1) GOTO 3
C
C   AFIT COMPUTATIONS
C
C   R IS PARTICLE RADIUS (IN METERS)
      R=C(1)/(S**5)+C(2)/(S**4)+C(3)/(S**3)
      R=R+C(4)/(S*S)+C(5)/S+C(6)+C(7)/SQRT(S)


C   CONVERT METERS TO MICRONS
      R = R*1.E+6
C
C   A IS ACTIVITY-SIZE FUNCTION
      A = 0.
      P = (ALOG(R) - ALOG(AL))/BT
      A = EXP(-.5*P*P)/(SQRT(6.283)*BT*R)
```

```
C
C    DR/DT IS DERIVATIVE OF R
        DRDT=-5.*D(1)/(S**6)-4.*D(2)/(S**5)-3.*D(3)/(S**4)
        DRDT=DRDT-2.*D(4)/(S**3)-D(5)/(S*S)-.5*D(7)/(S**1.5)
        DRDT  =DRDT*1.E+16
        G= A*ABS(DRDT)
        RETURN
C
  3     G=0.
        RETURN
C
C    WSEG COMPUTATIONS
C
  4     X=VX*S
        Q=ABS(X)
        H=1.+.196854*Q+.115194*Q*Q+.000344*Q**3+.019527*Q**4
        PHI=1. - 1./(2.*H**4)
        IF (X.LT.0.) PHI = 1.-PHI
        G = PHI*EXP(-S/TC)/TC
        RETURN
        END
C*****************************************************************
        FUNCTION BI(S)
        COMMON D(4),DM(5,40),D(7),AL,PT
        COMMON TC,SIGO,SIGH,SHR,SC,VX,TD,TM,TF,K,M,MD
        COMMON NN,W,TD
C    THIS FUNCTION CONVERTS DOSE RATE TO DOSE
C     USING THE WAY-WIGNER APPROXIMATION
C
        TA=S
        IF(TA.LT..1)TA=.1
        TE=TA+TD
        BI=5./(TA**.2)
        IF(TE.GT.TA)BI=BI-5./(TE**.2)
        RETURN
        END
C*****************************************************************
        FUNCTION SIGY(X)
        COMMON D(4),DM(5,0),D(7),AL,PT
        COMMON TC,SIGO,SIGH,SHR,SC,VX,TB, ,TF, M,MD
        COMMON NN,W,TD
C    THIS FUNCTION COMPUTES SIGMA Y, AS PER WSEG-10
C
        TS=X/VX
        IF(TS.GT.3.)TS=3.
        TR=1.+8.*TS/TC
        SIGY = SQRT(SIGO**2*TR + (SIGH*SHR*X/VX)**2)
        RETURN
        END
```

```
C************************************************************
      FUNCTION COEFF(ZK,N)
      DIMENSION A(250,9)
C   THIS FUNCTION READS THE DATA TAPE AND INTERPOLATES
C    FOR THE COEFFICIENTS NEEDED FOR THE GIVEN ALTITUDE ZK
C
      REWIND 4
      DO 10 I=1,250
      READ(4,100)(A(I,J),J=1,5)
      READ(4,101)(A(I,J),J=6,9)
 100  FORMAT(F[illegible].1,4E11.5)
 101  FORMAT(F[illegible].1,3E11.5)
      IF(ZK.LE.A(I,1))GO TO 11
 10   CONTINUE
 11   X2=A(I,1)
      X1=A(I-1,1)
      Y2=A(I,N)
      Y1=A(I-1,N)
      COEFF=((Y2-Y1)/(X2-X1))*ZK+((X2*Y1-X1*Y2)/(X2-X1))
      RETURN
      END
```

TABLE A-1

Glossary of Terms Within MULTI

INPUT PARAMETERS

D(I)	Contour value in dose or dose rate
YM	Yield of the weapons (in megatons)
FF	Fraction of yield due to fission
VX	Velocity of the wind (in miles per hour)
SHR	Crosswind shear (in hours^{-1})
NN	Number of bursts
W	Width of the field (in miles)
TD	Time of duration for dose computations (in hours)
AL	Alpha parameter from activity-size distribution curve
BT	Beta parameter from activity-size distribution curve

WSEG-10 PARAMETERS

HC	Nuclear cloud height (in kilofeet)
SIGH	Cloud thickness parameter
SIGO	Initial cloud radius parameter
TC	Time constant
SC	Source normalization constant

TABLE A-1 (Cont'd)

COMPUTATION PARAMETERS

ZK	Nuclear cloud height (in kilometers)
C(J)	Coefficients for AFIT g(t) computation
DT	Interval along hot line
TM	Time of maximum g(t)
TB	First time of occurrence of desired dose on hot line
TF	Final time of occurrence of desired dose on hot line
T	Time (in hours)
X	Downwind distance (in miles)
Y	Crosswind distance (in miles)
F	Cumulative normal function
FY	Crosswind distribution of activity
Q	Dose or dose rate
A	Crosswind mileage counter
MAXW	Crosswind limit of computation

FUNCTION G(S) PARAMETERS

R	Particle radius (in meters)
A	Activity-size function
DRDT	Change in particle radius with respect to time
PHI	Cumulative normal function

TABLE A-2

Interactive Inputs

ENTER M (0 or 1), MD (0 or 1), AND N (# CONTOURS) = 1,1,1

ENTER CONTOUR VALUES = 1500

ENTER YIELD, FRACTION, WIND LEVEL, AND WIND SHR = 1,.5,35.1

ENTER # OF BURSTS = 4600

ENTER N-S WIDTH OF FIELD = 190

ENTER TIME OF DURATION = 0

ENTER ALPHA AND BETA = 37,1.528

TABLE A-3

Sample Output

[illegible]
[illegible]
[illegible]
[illegible]
[illegible]

1	[illegible]	[illegible]
2	110.[illegible]	[illegible]
3	217.[illegible]	[illegible]
4	[illegible]	[illegible]
5	[illegible]	[illegible]
6	[illegible]	[illegible]
7	[illegible]	[illegible]
8	[illegible]	[illegible]
9	[illegible]	[illegible]
10	[illegible]	[illegible]
11	1072.9	[illegible]
12	[illegible]	[illegible]
13	[illegible]	[illegible]
14	[illegible]	[illegible]
15	[illegible]	[illegible]
16	1607.7	[illegible]
17	1714.6	[illegible]
18	1821.[illegible]	[illegible]
19	1928.5	[illegible]
20	2035.4	115.4
21	2142.[illegible]	107.4
22	2249.3	[illegible]
23	2356.3	94.[illegible]
24	2463.[illegible]	85.7
25	2570.2	76.[illegible]
26	2677.1	0.9

Vita

John F. Crandley, Jr. was born on 25 November 1951 in Pittsburgh, Pennsylvania. He graduated from Milford High School in Milford, Connecticut in 1969, and attended the U.S. Air Force Academy where he received the degree of Bachelor of Science (Chemistry) in June 1973. After graduation, he attended Undergraduate Navigator Training at Mather Air Force Base, California, which he completed in May 1974. He then attended B-52 Bombing/Navigation School. He was assigned as a B-52G Navigator and Radar Navigator between January 1975 and August 1979 at Griffiss Air Force Base, New York. He entered the Strategic and Tactical Sciences program, School of Engineering, Air Force Institute of Technology, in August 1978.

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Fallout

MX

Multiple Bursts

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A method is developed for calculating fallout deposition downwind from a massive nuclear attack on a small target area over a short time span. This is accomplished using existing smear codes and replacing their existing horizontal activity distribution with an approximating function. This function is the difference between two cumulative normal functions which are shown to result from superposition of individual bursts. A comparison is made between

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BLOCK 20: ABSTRACT (Cont'd)

the contours predicted by this new code and contours predicted by the old, time-consuming, iterative procedures. The new code has been employed in several different scenarios involving the proposed MX field to determine the resulting dose contours from a massive attack against that field.

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